MANAGING MERCURY, CADMIUM, AND LEAD
IN SPENT HOUSEHOLD BATTERIES

by

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ABSTRACT

In the U.S., one of the major end uses for mined mercury, cadmium and lead is in batteries and household batteries (ie. button and cylindrical shaped dry cells, and lead acid automotive type batteries) are the primary source of cadmium and lead in municipal solid waste. Mercury, cadmium and lead serve no known useful functions in the human body and are considered to be highly toxic in various forms. Mercury and lead affect the central nervous system and have been known to cause brain damage, most tragically in children. Cadmium is a probable carcinogen when inhaled, and its ingestion has been linked to a condition of severe bone weakening. Although the precise mechanisms of toxicity are somewhat unclear, there is little doubt that mercury, cadmium and lead are extremely hazardous to human health and that exposure to these metals should be kept to an absolute minimum.

This thesis is about the risks from disposing mercury, cadmium and lead in municipal solid waste, and the options available for reducing or managing mercury, cadmium and lead in spent household batteries.

Thesis Supervisor: Dr. John Ehrenfeld

Introduction

Since the mid 1970's, researchers in the field of environmental biogeochemistry have expressed a great deal of concern about the level of toxic metals released in the environment by industrial societies.[1] Heavy metals such as mercury,cadmium and lead serve no known useful functions in the human body and are extremely toxic in various forms, yet we release hundreds of tons of these metals each year to the air, water and soil through the production, use and disposal of heavy metal bearing products.

In the case of mercury, cadmium and lead, the primary use of these metals in the U.S. is in batteries (ie. dry cell batteries used in radios, toys and appliances, and wet cell lead acid batteries used in automobiles, boats and motorcycles), and batteries appear to be the major source of mercury, cadmium and lead in municipal solid waste. What are the risks from disposing household batteries as municipal solid waste? What can we do to reduce these risks? This thesis describes these risks, and offers a strategy for managing heavy metals in spent household batteries.

But first, a little context.

Current Battery Management Policies in the U.S. and Abroad

European governments have been concerned about heavy metals in household batteries for many years now, and countries in Western Europe have been the most progressive in setting

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[1] See O. Nriagu series on toxic metals in the environment, Elsevier Press, Holland.

stringent battery management policies. For example, the Swiss and Swedish governments have banned the sales of batteries containing more than 0.15% (Switzerland)[2] and 0.025% (Sweden)[3] mercury after 1990,[4] and both governments require battery manufacturers to label certain types of batteries with the International Standards Organization (ISO) recycling symbol. In addition, the Swedish government has imposed a per kilogram tax on dry cell batteries (amounting to 15% to 20% of the retail price) to fund recycling research.[5]

In the U.S., federal efforts to control heavy metals in spent batteries have focused exclusively on the lead acid automobile type of battery and not on the small, consumer dry cells. Federal solid waste management regulations categorize spent lead-acid batteries as a special type of "recyclable material" (40 CFR 261.6) which carries handling requirements which are similar to, but less exhaustive than, the handling requirements for hazardous wastes. Other types of consumer batteries fall under the category of "household wastes" (40 CFR 261.4 (b) (1)), which makes them exempt from all hazardous waste management requirements, regardless of their components.[6]

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[2] Europile, "Primary Batteries in Waste and the Environment: Position Paper No. II", 1988.

[3] Correspondence from Thomas Lindhqvist, University of Lund, Sjobo, Sweden.

[4] Alkaline batteries produced in Europe contained roughly 0.3% mercury by weight in 1988. (Europile, Ibid.)

[5] Europile, Ibid.

[6] One exception is the lithium battery. Congress has instructed the Environmental Protection Agency (EPA) to determine by February of 1986 whether the lithium battery should be listed as a specified hazardous waste for its reactivity (RCRA Section 6921 (e)(2)), however the EPA has not followed through with this mandate.

Despite the lack of a federal mandate for special handling of dry cell batteries, several local and regional bodies across the country have sponsored efforts to segregate spent dry cell batteries from other types of wastes and inform the public of the risks that heavy metals in batteries pose. The New Hampshire/Vermont Solid Waste Project has been credited with implementing the first comprehensive collection and information program for dry cell batteries in the U.S., and their retail dropoff program has served as a model for other locally based efforts. As of November, 1988, dry cell battery collection programs were being implemented in the following regions: the New Hampshire/Vermont solid waste district; Hennepin County, Minnesota; Southwest Missouri; and Bellingham, Washington. [7]

Why Collect Batteries?

The reasons for collecting spent lead acid automotive type batteries are obvious: they are hazardous, they are recyclable, and they contain valuable resources which make them economic to recycle. With spent dry cell batteries, the situation is less clear. They contain toxic metals, but they are small; they are recyclable, but only a few types -- mercuric oxide button cells, silver oxide button cells, and nickel cadmium rechargeable batteries -- are currently profitable to recycle. So why are communities in the U.S. and abroad collecting dry cell batteries?

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[7] Marie Steinwachs, "Battery Collection Programs", presented at the 1988 Conference on Household Hazardous Waste Management in Boston.

The primary reason in most instances has been to keep batteries out of municipal waste incinerators. Most dry cell batteries contain either mercury, cadmium or lead, three toxic metals which share the property of being highly volatilized by the process of incineration. Once volatilized, mercury, cadmium and lead are released in readily dispersible forms, either as inhalable emissions, or as fine, leachable particles in incinerator ash. The assumption (with much basis for support) is that by collecting spent batteries prior to incineration, communities can significantly reduce heavy metal emissions and the concentration of heavy metals in ash from municipal waste incinerators.

A second reason for collecting in spent batteries is to make use of the resources that batteries contain. In Japan, a country with few natural resources (but no shortage of technical ingenuity), the resource value has been described as the primary impetus behind national efforts to promote the collection of dry cell batteries.[8] If metals can be mined from batteries at an economic and environmental cost lower than the cost of mining from the earth, then it makes sense to view batteries as a resource rather than a waste.

Finally, waste managers in the U.S.[9] and in Japan are beginning to see a connection between the existence of heavy metals in the waste stream and the siting of municipal waste

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[8] "Japan collects batteries for two reasons. First, as with most other recovered materials, to conserve resources. ... The second reason is the public's concern about hazardous mercury emissions, despite the absence of substantiating health effect data." From Hershkowitz and Salerni, *Garbage Management in Japan: Leading the Way,* New York: INFORM, Inc., 1987.

[9] In the NH/VT Solid Waste District and in Bellingham, Washington, incinerator operators have been instrumental to the launch of battery collection programs.

management facilities, particularly incinerators. In Japan, waste managers have suggested that collecting spent batteries reduces not only emissions, but also the fear over emissions, particularly mercury emissions, and the resistance to siting engendered by this fear.[10] Thus Japanese communities are collecting spent batteries despite the fact that Ministry of Health and Welfare believes that the incineration of spent batteries mixed with other types of waste does not pose threat to human health or the environment.[11]

Why is the Issue Ripe Now?

Concern over the disposal of spent batteries has been on the policy agenda in Europe and Japan for many years now, yet in the U.S., issue is just beginning to reach fruition. We can rationalize that in the U.S., we don't incinerate as much of our waste (on a percentage basis) as our European and Japanese counterparts,[12] however this situation is changing. With municipal waste incinerators being planned and constructed in regions throughtout the country, the time is more than right to look into taking action.

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[10] Hershkowitz and Salerni, Ibid.

[11] Hershkowitz and Salerni, Ibid.

[12] The European Community as a whole burns 23% of its waste; Japan burns 65% of its waste; the U.S.burns about 10% of its waste. (McIlvaine, "Incineration & APC Trends In Europe", *Waste Age*, January, 1989.)

The Contents of this Thesis

Much of the discussion on the hazards of household batteries has focused on the following issues: What are the risks from incinerating spent batteries? What risks does landfilling pose? What options do we have for managing heavy metals in spent batteries? And finally, what specific policy actions should we take to ensure that spent batteries are managed in the safest, most efficient way? In this thesis I have chapters on each of these topics, with two additional chapters: one which describe the health effects of exposure to mercury, cadmium and lead, and one which describes trends in the use of mercury, cadmium and lead in batteries.

This thesis does not attempt to be a formal risk assessment of the disposal of spent batteries. Even if I was qualified to perform such a task, much of the data required is sketchy or not available (to my knowledge), for example: comprehensive data on landfill leachate composition that controls for the possibility of hazardous waste having been dumped at the site; recent, comprehensive data on U.S. emissions of mercury and cadmium from waste incineration; the percentage of mercury in municipal solid waste contributed by batteries, etc.... However, I do believe that there is enough information provided in this thesis to justify action, even if that action is a plan for a more pointed study, taking into account the conclusions and suggestions provided here.

Chapter 1:

Health Affects from Exposure to Mercury, Cadmium and Lead

Heavy metals such as mercury, cadmium and lead are present in trace amounts everywhere, and we are exposed to them every day in food, air, and water. Our bodies appear to be able to accomodate minute, daily exposures to mercury, cadmium and lead without suffering visible harm; however, for heavy metals that are carcinogenic, daily exposures can cause invisible harm by increasing the cumulative risk of developing cancer; and for other metals, exposure to large sudden doses, or to moderate doses sustained over time can push the body level beyond the "threshold of safety"[1], allowing heavy metals to wreak havoc in the body by displacing essential elements and altering the structure of enzymes, membranes and other cell components.

This chapter briefly outlines some of the known human health effects of exposure to mercury, cadmium and lead.

Mercury

Mercury occurs in three major forms:

1) elemental mercury
2) inorganic mercury compounds
3) "organomercurials", a group which includes the highly toxic methyl mercury.

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[1] A threshold below which no harm occurs is postulated for toxic substances that do not cause cancer. Precisely where that threshold lies varies from individual to individual depending on such factors as gender, age, size, health, degree of nutrition.

While methyl mercury is very well absorbed after ingestion 95%, inorganic mercury is less well absorbed (10%), and elemental mercury is the least well absorbed. (0.01% or less) through the ingestion route. [2] However all three forms are well absorbed (about 80%) after inhalation .

Once absorbed, mercury travels through the blood to various organs. Inorganic mercury compounds tend to effect the kidneys and the digestive tract; elemental mercury and organomercurials primarily effect the central nervous system. [3] Methyl mercury is particularly toxic: it crosses the blood brain and the blood placenta barrier easily, and it accumulates in the brain of both adults and fetuses. In adults, exposure to methyl mercury can cause numbness, loss of control, impairment of hearing, salivation, convulsions, and paralysis. In a developing fetus, exposure to methyl mercury can cause psychomotor retardation, cerebral palsy , and, in severe cases, death. [4]

Mercury tends to bind to sulfhydryl groups, which are common in membranes and enzymes. It is suspected that methyl mercury damages brain cells by binding to DNA and RNA molecules, thus inhibiting protein synthesis. [5]

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[2] Magos, Laszlo, "Mercury", Chapter 35 in *Handbook on Toxicity of Inorganic Compounds,* Eds. Hans G. Seiler & Helmut Sigel, NY: Marcel Dekker, Inc., 1988.

[3] Carson, Bonnie, et al., *Toxicology and Biological Monitoring of Metals in Humans,* Chelsea, Michigan: Lewis Publishers, Inc., 1986.

[4] W. Eugene and Aileen M. Smith, *Minamata,* NY: Holt, Rinehard and Winston, 1975.

[5] Friberg, L., et al., *Handbook on the Toxicology of Metals,* 2nd Edition, Holland: Elsevier Science Publishers, 1986.

In 1956 in the fishing village of Minamata, Japan, 52 victims were stricken with a strange brain illness that caused spasms, convulsions, paralysis and even death. The symptoms appeared to be similar to the symptoms villagers had seen in cats and dogs in the area, which were often seen stumbling around, senseless, engaging in sudden wild frenzies before falling down and dying. They called this sickness "Cat's Dancing Disease", but it was later named Minamata Disease, although the affliction was not actually a disease but rather the result of methyl mercury poisoning. (W. Eugene and Aileen M. Smith, *Minamata,* NY: Holt, Rinehard and Winston, 1975.)

Cadmium

Cadmium is not well absorbed (5%), via the ingestion route, but anywhere from 10% to 50% of cadmium that is inhaled is absorbed through the lungs, with absorption being higher for finer particles.

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Inhaled cadmium is classified by the EPA as a "probable human carcinogen"[7]; Friberg et al. state that"long term exposure to low air levels may lead to chronic obstructive lung disease and possibly lung cancer."

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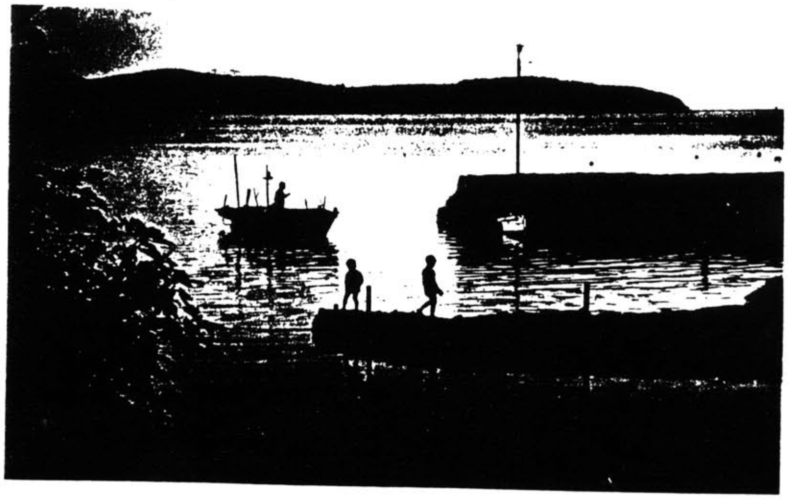
[6] Friberg et al., Ibid.

[7] Federal Register, Vol. 50, No. 200, October 16, 1985, p. 42001.

The body stores ingested cadmium in the liver and in the kidneys. When the level of cadmium in the kidneys exceeds a threshold amount, the kidneys can become seriously and permanently damaged, and this damage can lead to other problems, such as kidney stones. [8] Cadmium also interferes with calcium metabolism; excessive cadmium intake can lead to osteomalacia and osteoporosis, [9] and it is suspected to be a causative factor in the development of Itai-Itai Disease. (see caption)

Researchers suspect that cadmium exerts its toxicity by displacing zinc in enzymes. [10]



While World War II was taking its toll on Europe, a painful illness was afflicting residents (mostly women over 45 years of age) in the Toyama Prefecture, a city located on the Jinzu River in Japan. The symptoms were agonizing: pain in the bones, gradually spreading throughout the body; progressive skeletal deformation and awkwardness of gait; bone weakening to the extent that even the slightest pressures (such as caughing and sneezing) caused fractures; degeneration of the kidneys; difficulty sleeping and breathing from the constant pain. A local doctor who studied the outbreak gave it the name of "Itai-itai" disease, which is Japanese for "Ouch-ouch". (Nogawa, Chapter one in O. Nriagu, *Cadmium in the Environment: Health Effects*)

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[8] Carson et al., Ibid.

[9] Friberg et al., Ibid.

[10] Friberg et al., Ibid.

Lead

Lead is fairly well absorbed through the inhalation route, with absorption estimated be 50% or less depending on the size of the particles (finer particulates are better absorbed). Via the ingestion route, adults typically absorb only about 5% -15%, however children can absorb as much as 50%, with undernourished children absorbing the highest levels.[11] The fact that children's bodies absorb more of the lead they ingest means that lead is especially toxic for children.

The body normally accumulates lead in the bones, however lead that is not stored in the bones often effects the central nervous system. Like methyl mercury, lead crosses the blood brain and the blood placental barrier, although it does not travel quite as freely as methyl mercury.[12] It only takes a small amount of lead to cause serious, irreversible damage to the brain. Although the effects may be subtle, researchers note a definite pattern of learning disability, behavioral problems, lack of concentration, and general underachievement in children who have been exposed to mild or moderate amounts of lead.[13]

While the mechanisms behind lead's toxicity are not well understood, lead appears to do damage by attaching to cell membranes and interfering with mitochondria.[14]

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[11] Goyer, Robert A., "Lead", Chapter 31 in *Handbook on Toxicity of Inorganic Compounds,* Eds. Hans G. Seiler & Helmut Sigel, NY: Marcel Dekker, Inc., 1988.

[12] Friberg et al., Ibid.

[13] Loth,Renee, "When Will We Stop Poisoning Our Children? Lead Paint and the Law," *Boston Globe Magazine,* February 21, 1988.

[14] Friberg et al., Ibid.

Lead has been used as an additive in paint for many years in the U.S.. In fact, the federal government did not ban the use of lead paint in houses until 1978. In many older houses with peeling paint, young children have ingested chips of leaded paint and have suffered the effects of lead poisoning ranging from mild learning disabilities to severe, permanent brain damage and even death. Renee Loth points out that in mild cases of lead poisoning, the saddest effect maybe the "interfer[ence] with a child's potential". (Renee Loth, "When Will We Stop Poisoning Our Children? Lead Paint and the Law," *Boston Globe Magazine*, February 21, 1988.)

Chapter 2:

Trends in the Use of Mercury, Cadmium and Lead in Consumer Batteries

Consumer batteries are often described as being dry cells (batteries in which the electrolyte is a solid or gel) or wet cells (batteries in which the electrolyte is a free-flowing liquid), depending on the consistency of the electrolyte. Dry cell batteries tend to be small and either button, cylindrical, or rectangular shaped. [1] Wet cells tend to be larger and box shaped. There are basically eight types of dry cell batteries available to consumers today : **alkaline, zinc carbon, mercuric oxide, silver oxide, zinc air, lithium, nickel cadmium, and sealed lead acid.** Only one type of wet cell battery is widely available, the wet cell **lead acid battery** used for starting, lighting and ignition (SLI) of motor vehicles. The following tables list the active materials in each of these battery types:

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[1] Typical sizes include AA, AAA, C, D, 9-volt, and lantern.

Common Types of Consumer Batteries/1

Battery Type/2	Anode	Cathode	Electrolyte
Alkaline	Zinc	Manganese Dioxide	Alkaline
Solution/3			
Zinc Carbon/4 Chloride	Zinc	Manganese Dioxide or Zinc Chloride	Ammonium
Lithium/5 Solvent	Lithium Others	Sulfur Dioxide,	Non-aqueous
Mercuric Oxide Solution Button Cell	Zinc	Mercuric Oxide	Alkaline
Silver Oxide Solution Button Cell	Zinc	Silver Oxide	Alkaline
Zinc Air Solution Button Cell	Zinc	Oxygen (from air)	Alkaline
Nickel Cadmium Solution Rechargeable	Cadmium	Nickel Oxide	Alkaline
Sealed Lead Acid/5 Rechargeable	Lead	Lead Dioxide	Sulfuric Acid
(Wet Cell) Lead Acid/5 Automotive-type/6 Rechargeable	Lead	Lead Dioxide	Sulfuric Acid

1 Source: National Electrical Manufacturer's Association (NEMA), except where noted.

2 Typical shapes and sizes include button, cylindrical (AA, AAA, C, D), 9-volt, and/or lantern, unless otherwise noted.

3 Typical alkaline solutions include potassium hydroxide, sodium hydroxide.

4 This category includes "general purpose" LeClanche cells, and "heavy duty" and "super heavy duty" zinc chloride cells.

5 Source: *Handbook of Batteries and Fuel Cells,* Ed. David Linden, NY: McGraw-Hill, Inc., 1984.

6 Available in shapes and sizes for suitable for automobiles, tractors, motorycycles, scooters, and other purposes.

All batteries which have zinc anodes also have a small amount of mercury added to prevent the zinc from forming a gas with the other cell components. [2] This means that all of the batteries listed above except for the lithium battery contain either mercury, cadmium or lead.

This chapter describes current trends consumer batteries, including trends in consumer demand for batteries, trends in the use of mercury, cadmium and lead in batteries, and trends in battery recycling.

Trends in Consumer Demand for Batteries

Dry Cells:

Consumer demand for dry cell batteries appears to be on the rise. Unit sales of dry cell batteries have increased by five percent or more each year since 1983, as shown in the table below. The obsession we have with portability and miniaturization, as evidence by the growth of such products as portable phones, computers, and faxes; CD walkmans, watchmans, and videocams, etc. makes it easy to understand why.

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[2] There are a few exceptions. Polaroid Corp. has found a way to produce zinc carbon cells for its film packs without the use of mercury (Harry Fatkin, Polaroid); and a French battery producer has reportedly found an organic substitute for mercury for its zinc carbon cells; see section on mercury use.

Dry Cell Battery Sales/1

Year	% Increase Unit Sales from Previous Year	% Increase Dollar Sales/2 from Previous Year
1983	6.1	12.8
1984	5.3	8.8
1985	5.0	8.3
1986	5.6	9.4
1987	5.0	8.5
1988	5.4	8.7

1 Printed in June 20, 1988 issue of *Drug Store News.*
Source: A.C. Nielsen and NFO Consumer Purchase Diary.

2 The increase in dollar sales exceeds the increase in unit sales because of the trend toward the purchase of higher priced batteries.

On average, each person in the U.S. used about 8 dry cell batteries in 1988, [3] amounting to roughly 2 billion dry cells nationwide. Virtually all were discarded as municipal solid waste.

Wet Cells:

A general sense for the demand in lead acid SLI batteries can be obtained by considering the number of lead acid SLI batteries discarded. Since lead acid SLI batteries typically last three to four years, the number of batteries discarded reflects the demand for batteries three

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[3] Letter from Fred Nicholson (National Electrical Manufacturer's Association) to Don Seeberger (Hennepin County battery project).

to four years previously. The table below lists the number of batteries discarded in recent years.

Lead Acid SLI Batteries Discarded/1

Year	Units (Thousands)/2	% Increase in Units from Previous Year
1982	74,795	
1983	74,934	0.18
1984	64,615	-13.77
1985	67,756	4.86
1986	66,825	-1.37
1987	73,926	10.62
1988	81,937	10.84

1 Figures derived from data contained in Franklin Associates study "Characterization of Products Containing Lead and Cadmium in Municipal Solid Waste in the United States, 1970 to 2000", January, 1989. See appendix for derivation.

2 This table includes SLI batteries for passenger cars, tractors, marine and general utility vehicles, golf cars, motorcycles, scooters, all terrain vehicles, and miscellaneous others. Batteries for motorcycles, scooters, and all terrain vehicles assumed to last three years; all others assumed to last four years.

The numbers above suggest that the demand for lead acid SLI batteries has fluctuated widely in the first half of this decade. However, the consulting firm of Franklin Associates Ltd. projects that in the future, lead acid battery sales will increase by about 1% per year. [4]

The numbers above also indicate that in 1988, each person in the U.S. discarded an average of one third of a lead acid SLI battery, amounting to roughly 82 million lead acid SLI

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[4] Franklin Associates,"Characterization of Products Containing Lead and Cadmium in Municipal Solid Waste in the United States, 1970 to 2000", Franklin Associates, Prarie Village, Kansas, January, 1989.

batteries nationwide. Approximately 80% were recycled; the other 20% were disposed as municipal solid waste.[5]

Trends in the Use and Recycling of Mercury, Cadmium and Lead in Batteries

Mercury:

Mercury is used in two ways in consumer batteries:

1) As an antigassing agent in zinc anode cells[6]
2) As a primary component in the cathode of mercuric oxide cells

Up until 1985, zinc anode batteries typically contained about 1% mercury (by weight)[7] to prevent the zinc from forming a gas with other cell components. Since then, battery manufacturers have been able to reduce the amount of mercury needed to perform this function. While specific data on batteries manufactured in the U.S. are not available, the European battery manufacturer's association reports a reduction in the mercury content of alkaline cells from 1% in 1985 down to to 0.3% in 1988. [8] A French battery manufacturer, Cipel, has reportedly been able to produce a zinc chloride (a heavy duty type of zinc carbon)

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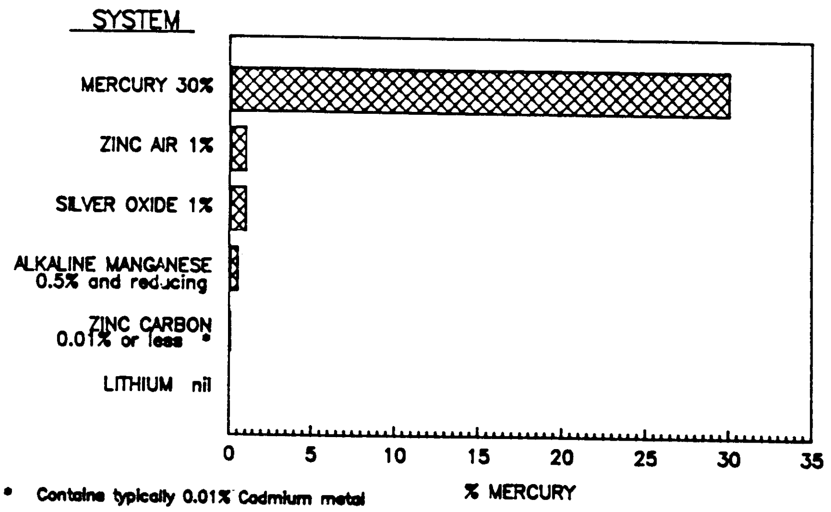
[5] The percent recycled is interpolated from Franklin Associates estimates. The report estimates the percent recycled in 1986 to be 80.3%;.the next percentage in the table is also 80.3%, for 1990.

[6] All of the batteries in table 1 except for the lead acid, nickel cadmium and lithium batteries have zinc anodes.

[7] Zinc carbon batteries may have contained less than this.

[8] Europile, "Primary Batteries in Waste and the Environment: Position Paper No. II", 1988.

battery that contains no mercury at all by using an organic substitute.[9] The following chart, taken from a European Battery Manufacturer's Association position paper, shows the mercury content (in percent weight) of batteries produced by European Battery Manufacturers in 1986:



Source: Europile, "Position Paper on EC Commission Proposal for a Council Directive Concerning Batteries and Accumulators Containing Dangerous Substances", 1986.

According to the National Electrical Manufacturer's Association (NEMA), U.S. manufacturer's have also achieved dramatic reductions in the use of mercury as an antigassing agent, and they expect these reductions to continue.[10] In fact, Polaroid Corporation has found a way to produce zinc carbon batteries for its film packs without using any mercury at all, and they are

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[9] ENDS Report 164, September, 1988.

[10] Raymond L. Balfour (Chariman, Dry Battery Section, NEMA), "Household Battery Disposal", presented at the 1988 Conference on Household Hazardous Waste Management in Boston.

currently searching for a substitute for mercury to make zinc carbon cells without mercury for all types of purposes.[11]

Mercury is also used as a major component in the cathode of a popular type of hearing aid battery -- the mercuric oxide button cell. Rayovac estimates the mercury content of mercuric oxide button cells to be about 35%-50% (by weight) in 1989[12]; the European Battery Manufacturer's Association reports a slightly lower mercury content. (See chart above) Since mercury is one of the energy-producing components of the cell, it is unlikely that the mercury content can be dramatically reduced without altering the energy output capacity of the cell.

The mercuric oxide button cell has been losing ground in recent years to a newer type of button cell, the zinc air button battery. (See chart below) Because the zinc air battery contains less mercury (1% to 3% by weight[13]) than the mercuric oxide button cell (35% to 50%), the zinc air battery is considered to be a less hazardous substitute. However, the difference in mercury content also affects the recyclability of these cells. The mercuric oxide button cell contains enough mercury to make its recovery profitable; the zinc air cell does not contain enough mercury for its recovery to be economic, given the current status of recycling technologies. In a third type of button cell, the silver oxide button battery, both the silver and

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[11] Conversation, Harry Fatkin, Director of Health, Safety and Environmental Affairs, Polaroid Corporation, Cambridge, MA.

[12] Letter from Raymond L. Balfour, Vice President, Rayovac Corp., Madison, WI.

[13] Europile Position Paper on EC Commission Proposal for Directive on Batteries, 1986; and Franklin Associates (1989) Ibid.

the mercury are economic to reclaim, not because of the mercury, but because of the silver. At least two companies in the U.S. reclaim mercury and silver from mercuric oxide and silver oxide button batteries.[14]

U.S. Hearing Aid Battery Sales

	Mercuric Oxide		Zinc Air		Silver Oxide	
Year	Units*	%Market	Units*	%Market	Units*	%Market
1981	50.9	71.8	9.9	14.0	10.1	14.2
1982	55.7	77.6	10.0	14.0	6.0	8.4
1983	56.5	78.0	12.3	17.0	3.6	5.0
1984	47.8	70.2	17.9	26.3	2.4	3.5
1985	45.2	66.3	22.0	32.3	1.0	1.4
1986	45.7	61.3	26.6	35.7	2.2	3.0
1987	45.5	57.8	31.6	40.2	1.6	2.0

* Units are given in millions.

Source: Rayovac Corporation, July 26, 1988

Because of reductions in the use of mercury as an antigassing agent, and substitution of zinc air cells for mercuric oxide cells in the button cell market, the U.S. battery industry has dramatically reduced the amount of mercury used in consumer batteries in recent years:

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[14] Mercury Refining Co., Inc. of Albany, NY, and Environmental Pacific of Oswego, OR.

Consumption of Mercury in Consumer Batteries
(In Short Tons)

Year	Consumption*
1983	752.8
1984	778.1
1985	696.4
1986	674.9
1987	432.6
1988	269.5
1989	167.9

* Consumption from 1987 onward based on battery industry projections.

Source: NEMA; Printed in Raymond L. Balfour, "Household Battery Disposal", presented at 1988 Conference on Household Hazardous Waste Management, Boston.

As the projections for 1987 onward show, the battery industry firmly expects this trend to continue. However, if people continue to use more dry cell batteries each year, and if, as Duracell predicts, alkaline cells (which have a higher mercury content than the zinc carbon cells) gradually displace zinc carbon cells in the market[15], there is always the possibility that mercury use will rise again over time.

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[15] Associated Press: "In 1985, alkaline batteries made up 62 percent of the sales, and are expected to reach a 75 percent share by 1990, according to Duracell spokesman John Bergman," (Newspaper article included in NH/VT Solid Waste Project info packet.)

Cadmium:

The major use of cadmium in dry cell batteries is in the nickel cadmium rechargeable battery. The rechargeable "NiCad" contains about 17% cadmium by weight.[16] Since cadmium is one of the energy-producing components of the cell, it is unlikely that the cadmium content can be dramatically reduced without altering the output capacity (per charge) of the cell.

Most nickel cadmium batteries are sold as built-in components of rechargeable devices (ie. vacuums, tools, appliances), however about 20% to 30%[17] are sold as free standing units. One free standing unit can replace dozens of zinc carbon and alkaline batteries, at a significant cost savings, if used to its potential.[18] Free standing nickel cadmium batteries appear to be gaining popularity among consumers.

Cadmium is also often contained in trace amounts in alkaline and zinc carbon batteries. There are two reasons for this. First, because cadmium and zinc tend to occur together in nature, refined zinc frequently contains cadmium as a trace contaminant[19]. Second, cadmium is sometimes added to zinc cans (up to 0.3%) to provide strength and corrosion resistance[20].

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[16] National Electrical Manufacturer's Association estimate.

[17] Rose, Michael V. (Rose Development Associates), "Commercial Considerations in the Collection and Recycling of Small Sealed Nickel-Cadmium Batteries", presented at the Fifth International Cadmium Conference, February, 1986.

[18] "Dry Cell Batteries," Consumer Reports, November, 1987.

[19] In fact, cadmium is rarely mined on its own; it is usually collected as a by product of zinc mining.

[20] *Handbook of Batteries and Fuel Cells,* Ed. David Linden, NY: McGraw-Hill, Inc., 1984.

Consumer nickel cadmium batteries are not currently recycled in the U.S., but they are being recycled abroad.[21] At least one battery reclaiming facility in the U.S.[22] accepts free standing NiCads, free of charge, and sends them abroad to be recycled. However, the amount recycled from U.S. batteries is insignificant. [23]

The consulting firm of Franklin Associates, Ltd. has estimated the amount of cadmium used to make consumer batteries from the year 1970 to the year 2000 in a report on sources of cadmium and lead in municipal solid waste.[24] According to their estimates, cadmium use in consumer batteries has been on the rise in recent years, and will continue to rise in the future, reaching about 150% of its 1986 level by the year 2000. (see table)

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[21] SAB NIFE plant, Oskarshamn, Sweden.
[22] Mercury Refining Co. of Albany, NY. There may be others as well.
[23] Franklin Associates (1989), Ibid.
[24] Franklin Associates (1989), Ibid.

Consumption of Cadmium in Consumer Batteries
(In Short Tons)

Year	Consumption*
1975	333
1976	1,019
1977	756
1978	919
1979	1,077
1980	792
1981	999
1982	889
1983	931
1984	943
1985	969
1986	1,268
1987	1,478
1988	1,531
1990	1,635
1995	1,933
2000	2,285

*Consumption adjusted for military/industrial diversions, manufacturing losses, and imports/exports. Estimates from 1986 onward based on projections.

Source: Franklin Associates, 1989.

The Franklin Associates study concluded that batteries are currently the largest source of cadmium in municipal solid waste, accounting for more than half of the cadmium discarded since 1980, and 52% of the total amount discarded in 1986[25].

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[25] Franklin Associates (1989), Ibid.

Lead:

The lead acid storage battery is by far the largest end use for raw lead in this country, accounting for 78% of the total U.S. consumption of lead in 1987. [26] According to Franklin Associates, roughly 80% of these batteries are used in motor vehicles (ie. cars, trucks, buses, motorcycles, etc.) for starting, lighting and ignition.

Lead is used as the major component of both the anode and the cathode in the sealed and the wet cell lead acid batteries, (See previous table on battery types and components) and also in the grid structure used to support the anode and the cathode. Both types of battery contain roughly 50% lead by weight. [27] Lead is also contained in trace amounts in zinc carbon, alkaline, silver oxide, and zinc air batteries, however this use is negligible compared to the other uses.

Sealed lead acid batteries function quite like nickel cadmium batteries and can be purchased as free standing units or as built-in components of rechargeable tools and appliances.[28] Unlike the nickel cadmium battery, the sealed lead acid battery is not widely available as a free standing unit and, according to Franklin Associates, recent sales of sealed lead acid batteries are "relatively insiginificant" compared to nickel cadmium battery sales. [29]

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[26] U.S. Bureau of Mines Minerals Yearbook, 1987.

[27] Franklin Associates, (1989), Ibid.

[28] Conversation with engineer at Gates Energy.

[29] Franklin Associates, (1989), Ibid.

In constrast, wet cell lead acid batteries are ubiquitous and can be found in virtually every car, truck, and motorcycle, scooter, motorboat, golf cart, and power wheelchair. In cars, boats and motorcycles they are used for starting, lighting and ignition functions, hence the name "SLI" battery. The amount of lead used per battery has been declining in recent years, from over 25 pounds in the mid 1970's to about 20 pounds in 1986 for automobile batteries, and from over 11 pounds down to 8.4 pounds for motorcycle batteries. [30] This decline is partly due to technological advances in the industry, and also partly due to a general reduction in the size of automobiles since the 1970's. [31] With manufacturers finding substitutes for the inactive lead used in the grid, [32] it seems likely that the lead use per battery will continue to decline.

According to Franklin Associates[33] , the total amount of lead in consumer SLI batteries has fluctuated in recent years, but is projected to increase by about 1% per year in the future. (See table)

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[30] Franklin Associates, (1989), Ibid.

[31] U.S. Bureau of Mines Minerals Yearbook, 1986.

[32] GNB of St. Paul, Minnesota has recently begun marketing a new type of lead acid automotive battery ("The Switch") that uses coated copper instead of lead for the grid. However, this battery does not contain less lead than other automobile batteries because it is really two batteries in one -- a main battery, and a small reserve battery , and the amount of active lead (lead in the anode and cathode) in the two batteries together adds up to the same amount of lead in a single lead acid battery with a lead-based grid. (Conversation, Mike Faulkner of GNB.)

[33] Franklin Associates (1989), Ibid.

Consumption of Lead in Lead Acid SLI Batteries/1
(In Short Tons)

Year	Automobile Type/2	Motorcycle Type/3	Total
1975	627,359	13,699	641,058
1976	732,820	11,868	744,688
1977	826,120	13,279	839,399
1978	854,186	13,327	867,513
1979	778,677	13,562	792,239
1980	668,509	14,521	683,030
1981	717,841	14,704	732,545
1982	687,067	14,657	701,724
1983	747,258	13,542	760,800
1984	808,576	13,622	822,198
1985	836,469	15,110	851,579
1986	836,154	12,782	848,936
1987	791,838	12,910	804,748
1988	817,177	13,039	830,216
1989	835,154	13,169	848,323
1990	845,176	13,301	858,477
1991	862,925	13,434	876,359
1992	871,554	13,568	885,122
1993	880,270	13,704	893,974
1994	889,072	13,841	902,913
1995	897,963	13,979	911,942
1996	906,943	14,119	921,062

1/ Figures from 1986 onward are based on projections; all figures are adjusted for manufacturing losses, imports, and exports.

2/ Automobile type includes batteries for cars, trucks, tractors, marine vehicles, general utility, golf car, and miscellaneous uses.

3/ Motorcycle type includes batteries for motorcycles, scooters, and all terrain vehicles.

Unlike the previous types of batteries described, the lead acid battery has a well established recycling chain in the U.S. and in fact, most lead acid SLI batteries are recycled. (See table below)

Recycling Rates for Lead Acid SLI Batteries

Year	Percent Recycled
1970	79.5
1971	75.4
1972	72.0
1973	69.5
1974	76.3
1975	66.0
1976	66.4
1977	72.9
1978	76.7
1979	85.4
1980	72.4
1981	61.9
1982	52.8
1983	52.3
1984	73.2
1985	69.7
1986	80.3

Source: Franklin Associates, "Characterization of Products Containing Lead and Cadmium in Municipal Solid Waste in the United States, 1970 to 2000," Franklin Associates, Ltd., Prairie Village, Kansas, January, 1989.

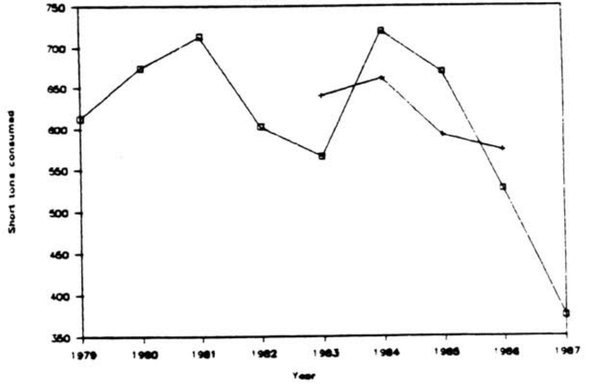
While most lead acid SLI batteries do get recycled, the recycling rate varies widely from year to year: In just the period from 1980 to 1986, the recycling rate fluctuated from a low of 52.3% to a high of 80.3%. As the diagrams below indicate the recycling rate for lead acid SLI batteries appears to be directly related to the commodity price for lead:

Even though most lead acid batteries are recycled, the Franklin Associates study concluded that lead acid batteries are the largest source of lead in municipal solid waste, accounting for 65% of the total amount discarded in 1986[34].

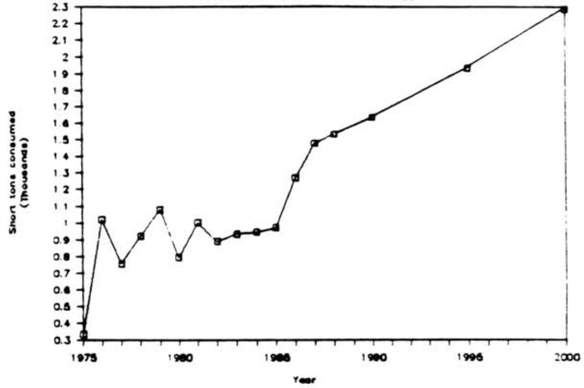
Summary

This chapter briefly reviewed trends in the usage of mercury, cadmium and lead in batteries. The following graphs, made from tables contained in this chapter, tell much of the story:

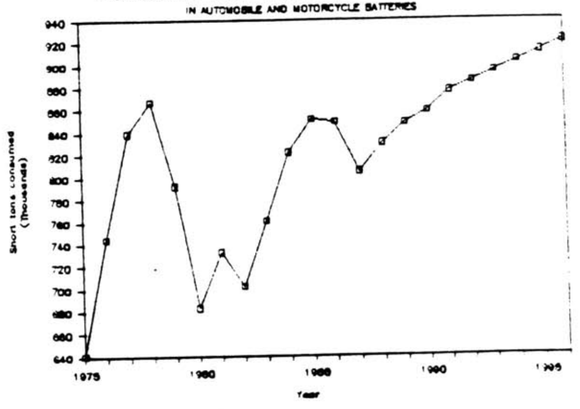
ESTIMATED U.S. CONSUMPTION OF MERCURY
IN CONSUMER BATTERIES



ADJUSTED U.S. CONSUMPTION OF CADMIUM
IN CONSUMER NICKEL–CADMIUM BATTERIES



ADJUSTED U.S. CONSUMPTION OF LEAD
IN AUTOMOBILE AND MOTORCYCLE BATTERIES



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[34] Franklin Associates (1989), Ibid.

Source reduction and substitution away from the use of mercury in batteries have resulted in dramatic decreases in the amount of mercury used in consumer batteries in recent years. However, the increase in the demand for dry cell batteries in general and for alkaline batteries in particular (which contain more mercury per cell than zinc carbon types) suggests that mercury usage may begin to rise again over time. The amount of cadmium used in consumer batteries has been rising rapidly in recent years, primarily due to the popularity of rechargeable nickel cadmium batteries, and this trend is expected to continue. Lead use in consumer batteries is also expected to increase over time, however the increase is projected to be slight and gradual.

A recent study on the sources of cadmium and lead in municipal solid waste implicates batteries as the major source for both of these metals, with nickel cadmium and lead acid batteries responsible for more than half of the cadmium and lead in the municipal waste stream in 1986.

APPENDIX

Units of lead acid SLI batteries was derived from the following data contained in Franklin Associates (1989):

Year	Gross Discards of Lead in Motorcycle Batteries/1 (short tons)	Lead/Battery in Discarded Motorcycle Batteries (lbs)	Gross Discards of Lead in Automobile Batteries/2 (short tons)	Lead/Battery in Discarded Automobile Batteries (lbs)
1982	13,562	10.0	854,186	23.7
1983	14,521	9.6	778,677	22.6
1984	14,704	9.8	668,509	21.7
1985	14,657	9.5	717,841	22.2
1986	13,542	9.3	687,067	21.5
1987	13,622	8.8	747,258	21.1
1988	15,110	8.8	808,576	20.6

1 Franklin Associates assumed a 3-year life span for "motorcycle" (including motorcycle, scooter, and all terrain vehicle) batteries.

2 Franklin Associates assumed a 4-year life span for "automobile" (including passenger car, tractor, marine, general utility, golf car, and miscellaneous) batteries.

From these tables it is possible to derive the following:

Year	Gross Discards of Lead in Motorcycle Batteries (thousand lbs)	Units of Motorcycle Batteries (thousands)	Gross Discards of Lead in Automobile Batteries (thousand lbs)	Units of Automobile Batteries (thousands)
1982	27,124	2,712	1,708,372	72,083
1983	29,042	3,025	1,557,354	68,909
1984	29,408	3,001	1,337,018	61,614
1985	29,314	3,086	1,435,682	64,670
1986	27,084	2,912	1,374,134	63,913
1987	27,244	3,096	1,494,516	70,830
1988	30,220	3,434	1,617,152	78,503

Year	Total Units Lead Acid SLI Batteries
1982	74,795,000
1983	74,934,000
1984	64,615,000
1985	67,756,000
1986	66,825,000
1987	73,926,000
1988	81,937,000

Chapter 3:
Risk of Exposure to Mercury, Cadmium and Lead from Landfilling Spent Batteries

The behavior of heavy metals in batteries disposed in landfills is somewhat difficult to predict since landfill conditions can vary so much from landfill to landfill. Such factors as landfill temperature, degree of aeration, degree of moisture, and character of codisposed waste may all effect the rate and extent to which metals are leached from waste and mobilized to contaminate surrounding soils and groundwaters. However, there have been some attempts to simulate what happens to heavy metals in batteries under "typical" landfill conditions, and I will describe these here. In addition, I have included some data on the heavy metal content of landfill leachate, with the assumption that household batteries are largely responsible for any contributions of mercury, cadmium and lead. [1]

Dry Cell Battery Experiments

In a study conducted in the late 1970's, British researchers attempted to simulate ordinary landfill conditions in a variety of experiments designed to elucidate what happens to mercury and cadmium in dry cell batteries over time as they are subjected to landfill leachate. [2] To do this, they set up three types of experimental conditions:

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[1] This is not unreasonable, considering that batteries are the major source of cadmium and lead in municipal solid waste (see chapter 2), and they are probably the major source of mercury as well.

[2] C.J. Jones, P.J. McGugan and P.F. Lawrence, "An Investigation of the Degradation of Some Dry Cell Batteries Under Domestic Waste Landfill Conditions," *Journal of Hazardous Materials,* Vol. 2 (1977/78), p. 259.

1) Batteries immersed in flasks of lab-made leachate for 100 days.
2) Batteries buried in an actual landfill for 7 months.
3) Pulverized batteries layered with pulverized waste in a column of distilled water for 3 months.

The immersion tests revealed that while some types of batteries corrode more rapidly than others, the amount of mercury dissolved in the leachate never (over the 100 day testing period) exceeded 0.01% of the total mercury content, even for batteries whose casings had completely corroded, and the amount of cadmium never reached the detection limit (0.01 ppm). This suggests that mercury and cadmium in batteries are not very soluble in landfill leachate.

The landfill burial study revealed that the corrosion rate in an actual landfill is much slower than the corrosion rate measured in the immersion experiment. The authors estimated that the lab conditions corroded the batteries about five times faster than the actual rate.

The column studies did not test for cadmium, but for mercury, the results reinforced what the immersion tests suggested: even when the mercury was exposed, less than 1% dissolved in the leachate over the 12 week study period. There was one exception: the pulvarized silver zinc battery column leached 5% of its mercury between the tenth and twelth week, however the authors suggested that this unusually high amount "may be a spurious result of little significance."

From these results, the authors concluded that "provided they are well mixed with household wastes and recommended disposal practices are employed, the presence of domestic arisings of primary dry cell batteries in landfill[s] presents no special threat groundwater quality." However, it is important to note that these experiments did not test the behavior of heavy metals in batteries over the long term, and this behavior may be quite different from the short term behavior.

In another British study recounted by Bromley et al.[3], researchers measured the ability of waste to absorb, or "attentuate" concentrations of dissolved cadmium. They passed a solution of dissolved cadmium through a 50 centimeter column of pulverized waste and measured the concentration of cadmium in the resulting effluent. The effluent invariably contained much lower concentrations of cadmium than the original solution: for a 100 mg/liter solution applied continuously to the column, the attentuation factor was calculated to be about 5 X 10 -3; for a 1000 mg/liter solution applied discreetly, the attenuation factor was calculated to be about 5 X 10 -4. Apparently waste is less effective at absorbing dissolved cadmium when it is applied continuously, as it would be in an actual landfill, than when it is applied intermittently. However, this experiment also suggests that even when cadmium is dissolved in leachate, its concentration may be significantly attenuated by waste before it reaches the base of the landfill.

These studies make it clear that several steps need to take place for mercury and cadmium in dry cell batteries to contaminate soils or groundwater. These steps include the following:

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[3] J. Bromley et al., "Environmental Aspects of the Release and Fate of Cadmium in Municipal Landfills, with Reference to the Use and Disposal of Nickel Cadmium Batteries and Pigmented Plastics," *Proceedings from Fourth International Cadmium Conference,* (Munich, West Germany), 1983.

1) Corrosion of batteries and exposure of metals.

2) Dissolving of metals into solution.

3) Attenuation of solution through waste.

4) Exit landfill to reach soils and groundwater.

While corrosion of the battery casing may occur over the short term (for some batteries less than 2 years), dissolution of mercury and cadmium over the short term is minimal (less than 0.01% for mercury, and undetectable for cadmium). Attenuation can further reduce the concentration of these metals in leachate, making it even less likely that mercury and cadmium contained in "domestic arisings" of dry cell batteries in landfills will reach soils and groundwaters in high concentrations in the short term.

However, these studies do not simulate what happens in the long term ie. 25 to 50 years. It is generally thought that landfill leachate becomes more acidic over time, and this may have a significant effect on the solubility of battery metals.

Landfill Leachate Composition

Another way to attack the problem is to consider the concentration heavy metals in leachate collected from municipal waste landfills. The most comprehensive data currently available on landfill leachate composition is contained in a 1988 EPA report to Congress entitled "Solid Waste Disposal in the United States".[4] In this report the EPA compiled data on the

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[4] EPA, Office of Solid Waste and Emergency Response, October 1988.

composition of leachate from 70 U.S. municipal waste landfills. Unfortunately for some landfills, important information such as the age, type of waste accepted, and the list of constituents for which tests were conducted were unknown, however for most of the landfills these variables were recorded.

62 of the 70 landfills were analyzed for inorganic (including heavy metals) constituents. The table below lists the number of sites at which mercury,cadmium and lead were detected, the concentration range, the median concentration, and the drinking water standard for that metal. The drinking water standard is used as a guideline for what the EPA considers to be a safe level for human consumption. As the EPA report points out:

"This analysis is very conservative because in all but the most extreme circumstances, municipal solid waste landfill leachates will become diluted in groundwater. "[5]

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[5] EPA (1988), Ibid.

Metal Concentrations in Municipal Waste Landfill Leachate*

Compound	#Sites at Which Detected	Concentration Range	Median Concentration	Drinking Water Std.
Mercury	16	0.0001 - 0.01	0.0006	0.002
Cadmium	31	0.007 - 0.15	0.0135	0.01
Lead	45	0.005 - 1.6	0.063	0.05

*All concentrations given in units of parts per million.

Source: EPA, "Solid Waste Disposal in the United States"
Office of Solid Waste and Emergency Response, October 1988.

The table indicates that the median concentration of mercury in all landfills in which it was detected was less than the drinking water standard for mercury; the median concentration of cadmium was slightly higher than the drinking water standard for cadmium; and the median concentration of lead was slightly higher than the drinking water standard for lead. However the ranges indicate that mercury was detected at five times the drinking water standard for mercury, cadmium was detected at fifteen times the drinking water standard for cadmium, and lead was detected at over thirty times the drinking water standard for lead. This suggests that there may be a problem in some landfills with cadmium and lead.

One problem with drawing conclusions from the data is that many of these landfills were in operation prior to the passage of hazardous waste laws (RCRA) which banned the disposal of hazardous wastes in municipal waste landfills. To control for this factor, the EPA also broke down the data into pre-1980 landfill and post-1980 landfill data sets. The post-1980 landfills presumably did not accept what we now call "hazardous wastes", while the pre-1980 landfills may have accepted them. The EPA did not have enough information to include mercury in the breakdown, however the results for cadmium and lead are listed below.

Metal Concentrations in Municipal Waste Landfill Leachate* Broken Down by Starting Date of Operation

Pre-1980 Start Date:

Compound	#Sites at Which Detected	Concentration Range	Median Concentration	Drinking Water Std.
Cadmium	15	0.002 - 0.15	0.018	0.01
Lead	24	0.031 - 1.6	0.072	0.05

*All concentrations given in units of parts per million.

Source: EPA, "Solid Waste Disposal in the United States"
Office of Solid Waste and Emergency Response, October 1988.

Post-1980 Start Date:

Compound	#Sites at Which Detected	Concentration Range	Median Concentration	Drinking Water Std.
Cadmium	5	0.003 - 0.02	0.0065	0.01
Lead	5	0.007 - 0.15	0.046	0.05

*All concentrations given in units of parts per million.

Source: EPA, "Solid Waste Disposal in the United States"
Office of Solid Waste and Emergency Response, October 1988.

Although it is risky to draw conclusions from such a small sample of post-1980 sites (five for cadmium and five for lead), the data suggest that the cadmium and lead concentrations of leachate from post-1980 landfills are lower than the cadmium and lead concentrations of leachate from pre-1980 landfills. However, the ranges indicate that even in post-1980 landfills, cadmium was detected at twice the drinking water standard and lead was detected at three times the drinking water standard.

Overall, the median concentrations suggest that mercury, cadmium and lead concentrations in landfill leachate are in the range of the drinking water standards for these metals and are thus not likely to cause harm to human health. However, the ranges suggest that in some landfills, lead and cadmium concentrations have reached levels that may cause harm if not sufficiently diluted. The concentrations of cadmium and lead appear to be higher in leachate from older landfills, but this may be partially due to the fact that older landfills accepted more types of waste than municipal landfills accept today.

Chapter 4:

Risks from Incineration of Mercury, Cadmium and Lead in Municipal Solid Waste

It is common knowledge that we in the U.S. are in the midst a "garbage crisis". While the amount of waste discarded each year continues to rise[1], the number of active landfills has dropped sharply in recent years[2], and the siting of new landfills has become a difficult if not impossible task. With landfills throughout the country approaching their capacity limits, cities and towns are increasingly turning to waste incineration (with energy recovery) as means for reducing their disposal needs.[3]

This chapter focuses on one category of risks from municipal waste incinerators: the risks from incinerating the heavy metals mercury, cadmium and lead. I have limited my scope to mercury, cadmium and lead mainly because these metals are concentrated in spent batteries, but also because mercury, cadmium and lead share properties which make them more likely than many other types of metals to be released and cause harm. The first part of this chapter describes these properties and what happens when you incinerate mercury, cadmium and lead. The rest of this chapter describes how

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[1] See figure 1 in the appendix.

[2] According to Newsweek, "more than two thirds of the nations landfills have closed since the late 1970's; one third of those remaining will be full in the next five years." (November 27, 1989)

[3] In 1980, about 2% of the municipal solid waste in the U.S.was incinerated with energy recovery; by 1986, the percentage was about 7%, and by the year 2000, the percentage is expected to reach about 19%. See figure 1 in the appendix. Ocean disposal and incineration without energy recovery are not included in the total because they are considered to be negligible relative to landfill disposal. (EPA, "Solid Waste Disposal in the United States," October, 1988)

mercury, cadmium and lead are released from municipal waste incinerators and the ways that these releases can expose people and cause harm.

The Behavior of Mercury, Cadmium and Lead during Incineration

Compared to other metals, mercury, cadmium and lead have relatively low boiling points and high vapor pressures, and these properties make them more likely than other metals to become volatized by the process of incineration. Metals that are highly volatized tend to be concentrated in the emissions and fly ash; metals that are not highly volatized tend to remain in the bottom ash. [4]

Most incinerators in the U.S. are required to operate at a minimum temperature of 982 degrees C (1800 degrees F)[5], a temperature which is higher than the boiling points for mercury (B.P. 357 C) and cadmium (B.P. 765 C), but lower than the boiling point for lead (1740 C). This, combined with the high vapor pressure for these metals, largely explains why mercury and cadmium tend to be concentrated in the fly ash and emissions, while lead tends to be dispersed throughout all of the products of incineration. The diagrams below, from Brunner and Monch[6], illustrate the partitioning of

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[4] Emissions are the vapors and particulates released from the stack; fly ash is the ash captured in particulate control systems such as baghouses and electrostatic precipitators; bottom ash is the ash that remains on the bottom of the incineration combustion chamber, along with any non-combusted material.

[5] This temperature is required to break down organic pollutants such as PCB's, etc. McInnes and Kohl, "Heavy Metal Emissions from Resource Recovery Facilities, June 1987, presented at Sixth Annual New England Resource Recovery Conference and Exposition, Manchester, NH, June, 1987.

[6] Brunner, Paul H. and Hermann Monch, "The Flus of Metals Through Municipal Solid Waste Incinerators," *Waste Management and Research* (1986), pp. 105-119.

mercury, cadmium and lead (plus iron, for comparison) between emissions, fly ash and bottom ash in two sample Swiss incinerators:

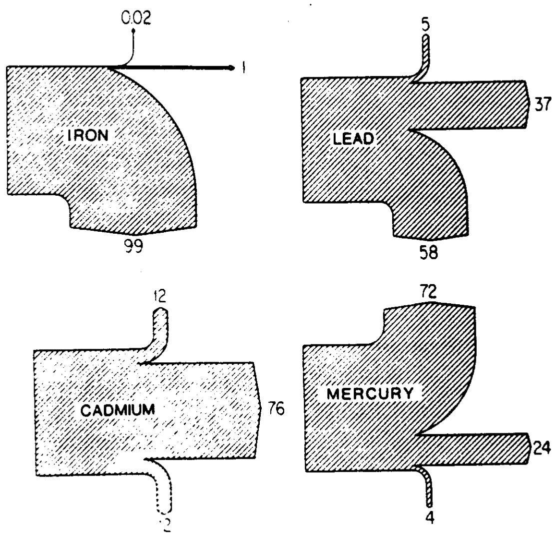

Fig. 7. The partitioning of metals by muncipal solid waste incineration. ↑, Flue gas; →, electrostatic precipitator dust; ↓, slag.

The incinerators tested operated at 900 degrees C and utilized a water spray cooling system and an electrostatic precipitator to control for stack emissions. Most new incinerators also have acid gas scrubbing systems, which tend to reduce metal emissions while increasing the concentration of metals in fly ash.

Because of its low boiling/condensation point, mercury tends to be released from the stack as a vapor phase emission. However cadmium and lead tend to condense on fine particles after leaving the combustion chamber, [7]and these fine particles are readily inhalable when released as emissions and soluble in leachate[8] when captured and landfilled as ash.

Risks from Cadmium and Lead in Municipal Waste Incinerator Ash

The Environmental Protection Agency measures the leachability of toxic metals in waste using the Extraction Procedure (EP) Toxicity Test. In this test, waste is exposed to a slightly acidic, aqueous leaching medium for 24 hours, then the liquid extract is tested for concentrations of eight toxic metals. If the concentration of any of the eight metals is found to be more than one hundred times the drinking water standard for that metal, then the waste is considered to be Hazardous Waste.

The Environmental Defense Fund recently summarized the results of previously published EP Toxicity tests on municipal waste incinerator ash in a memo addressed to "Parties with interest in Municipal Incinerator Ash"[9]. The summary aggregates data from over 1800 samples, ash indicated below (see table).

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[7] See Greenberg et al., "Composition and Size Distribution of Particles Released in Refuse Incineration", *Environmental Science and Technology,* vol .12, no. 5, May (1978), pp. 566-573; and also Wadge et al., "The Concentrations and Particle Size Relationships of Selected Trace Elements in Fly Ashed from U.K. Coal-Fired Power Plants and a Refuse Incinerator," *The Science of the Total Environment, 54 (1986) pp. 13-27.*

[8] Fine particles tend to be more soluble in liquids than large particles because they have a higher surface area to volume ratio; fine particles also stay in suspension longer than large particles, enabling them to be transported even when not dissolved.

[9] Memo dated February 19, 1989, from Richard A. Denison, Ph.D., Scientist, Toxic Chemicals Program.

ENVIRONMENTAL DEFENSE FUND

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February 19, 1989

SUMMARY OF EXTRACTION PROCEDURE TOXICITY TEST DATA ON MSW INCINERATOR ASH

	LEAD	CADMIUM	EITHER
FLY ASH: 23 Facilities			
No. of Samples Analyzed	185	97	185
No. of Samples Over EP Limit	168	94	173
% of Samples Over EP Limit	91%	97%	94%
Mean of All Samples (mg/L)	22.0[a]	37.3	--
No. of Facilities Over EP Limit[b]	20	21	22
Mean of Facility Means (mg/L)	23.4	31.8	--
BOTTOM ASH: 22 Facilities			
No. of Samples Analyzed	773	271	773
No. of Samples Over EP Limit	276	5	278
% of Samples Over EP Limit	36%	2%	36%
Mean of All Samples (mg/L)	6.39	0.25	--
No. of Facilities Over EP Limit	9	1	9
Mean of Facility Means (mg/L)	7.18	0.41	--
COMBINED ASH: 46 Facilities			
No. of Samples Analyzed	883	756	883
No. of Samples Over EP Limit	345	90	354
% of Samples Over EP Limit	39%	12%	40%
Mean of All Samples (mg/L)	6.46	0.56	--
No. of Facilities Over EP Limit	21	5	21
Mean of Facility Means (mg/L)	6.26	0.47	--

---

[a] Underlined values exceed EP limits defining a hazardous waste:

lead: 5.0 milligrams per liter (mg/L)
cadmium: 1.0 mg/L

[b] Number of facilities for which mean of all available samples exceeds limit

NOTE: Due to the large number of individual samples analyzed from certain facilities, the aggregate data tend to be skewed and overly dependent on the quality of ash from those few dominating facilities. Caution should be exercized in drawing conclusions about overall exceedance rates.

The memo attached to the summary states:

- for fly, bottom and combined ash, the averages of all samples exceed the regulatory limit defining a hazardous waste for lead;
- for fly ash, the average of all samples exceeds the regulatory limit for cadmium as well;
- virtually every fly ash sample tested has exceeded regulatory limits, and almost always for lead and cadmium.
- a large fraction of all bottom and combined ash samples exceed the regulatory limit for lead, and significant numbers for cadmium as well.

In other words, fly ash tends to have the highest leachable concentrations of cadmium and lead, but bottom ash also often has high leachable concentrations of lead.

How might people be exposed to cadmium and lead in incinerator ash? There are several possible pathways of exposure:

1) **People may be exposed to cadmium and lead dusts during transportation and handling of ash.** Fly ash dusts are particularly harmful since cadmium and lead in fly ash tends to be concentrated on fine particles which are readily inhalable.

2) **If the ash is disposed in an unprotected landfill or monofill, people may be exposed by drinking contaminated groundwater or by eating plants grown on contaminated**

soils. Cadmium and lead from incinerator ash are readily uptaken from soils in barley and cabbage plants tested. [10]

3) **If the ash is utilized in ashpalt or construction materials, people may be exposed to lead and cadmium dusts generated from normal wear and tear, and also from the dusts created during demolition.** On the issue of ash reuse/recycling, the Environmental Defense Fund has pointed out the following:

> Ash reuse/recycling involve potential exposures that extend well beyond those from ash disposal, both in magnitude and duration. ... Reuse of ash (e.g., in road building or construction activities) may only postpone rather than eliminate exposures. [11]

Other scenarios could also be imagined, but the basic issue in all of these scenarios is that once these cadmium and lead are concentrated in ash, and especially in the fine particles of ash, they are easily mobilized and are likely to cause exposure and harm.

Risks from Mercury Emissions from Municipal Waste Incinerators

Because mercury has such a low boiling point, it tends to remain in a vapor phase throughout the incineration process, and since vapors are not well captured by pollution control equipment, mercury tends to be released as an emission. Even incinerators equipped with"state of the art"

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[10] A. Wadge and M. Hutton, "The Uptake of Cadmium, Lead and Selenium by Barley and Cabbage Grown on Soils Amended with Refuse Incinerator Fly Ash," *Plant and Soil*, Vol. 96 (1986), pp. 407-412.

[11] EDF paper, "Prerequisites for Proper Implementation of Ash Treatment," undated.

emission control systems[12] frequently emit as much as 65% of the mercury vaporized[13] directly to the environment.

In 1984 the EPA assessed the risk of exposure to mercury emissions from waste incineration as part of its review of the national mercury emission standards. [14] Assuming the same mercury content of waste and the same load capacity for incinerator plants as in 1974, the EPA concluded that "emission levels from these plants would not cause the ambient concentration guideline to be exceeded;" therefore they did not set a mercury emission standard for municipal waste incinerators.

The EPA analysis considered the risks from direct exposure to mercury emissions from waste incineration, however it did not consider the risks from indirect exposure, ie. exposure to mercury after it has been deposited on land or in lakes or entered the food chain. A Swedish review on the fate of atmospheric mercury in the environment indicates that a small fraction (less than 10%) of the mercury emitted to the air from point sources is deposited in a local area, within 10 kilometers of the source; the rest is deposited regionally or even on a hemispheric scale. [15] Once deposited, mercury can be directly ingested in dust or in soil, but the greatest risk is posed by mercury deposited in lakes. Microorganisms in lakes uptake mercury in its deposited forms and convert it to the form most toxic to humans, organic methyl mercury. Unlike many other types of pollutants, methyl mercury is biomagnified up the food chain, which means that it becomes more highly concentrated at each trophic

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[12] The EPA and many states consider acid gas scrubbing followed by electrostatic precipitation to be the "state of the art" in emissions control for municipal waste incineration.

[13] Virtually all of the mercury in the waste stream is vaporized; the Brunner and Monch diagrams indicate that only 4%of the mercury remains in the bottom ash.

[14] EPA, "Review of National Emission Standards for Mercury", EPA-450, December 1984.

[15] Lindqvist, Oliver, "Atmospheric Mercury -- A Review," *Tellus* (1985), 37B, pp. 136-159.

level. Fish sized for human consumption can accumulate levels of mercury many times more concentrated than the level of mercury in the lake itself. Thus, even in lakes that do not seem highly polluted, the fish may contain levels of mercury that are hazardous to consume. [16]

The problem of methyl mercury accumulation in fish from airborne sources is exacerbated by two other factors: [17]

1) The presence of oxidizing pollutants such as ozone increases the deposition rate of elemental mercury (the most common form of mercury emitted) by oxidizing it to readily depositable forms.

2) The acidification of lakes (brought about by acid rain) tends to increase the degree of mercury uptake by fish.

Tests on the deposition rate of mercury in pristine regions of Sweden indicate that the deposition rate of mercury in the past 100 years has increased by a factor of 10 in Southern parts of the country, and by a factor of 2 in the northern parts. Swedish researchers believe that most of the increase is from point sources throughout the European continent. All told, emissions from point sources of mercury in Sweden and throughout Europe, combined with increased deposition of mercury caused by the presence of oxidizing pollutants in the air and an increase in mercury uptake in acidified lakes have caused mercury levels in Swedish lake fish to rise to a point where the Swedish food agency

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[16] Lindqvist, Oliver, "Occurrence and Turnover of Mercury in the Environment -- A Swedish Research Project", paper written in 1987 or later (undated) at the Department of Inorganic Chemistry, Chalmers University of Technology and the University of Goteborg. Detailed information on the Swedish mercury research project is available through the Swedish Environmental Protection Board,Solna, Sweden.

[17] Lindqvist, Oliver, (1987+), Ibid.

has issued warnings against eating lake fish at all for pregnant women, and for certain types of lake fish, more than once per week for others. [18]

To avoid a similar situation in the U.S., it makes sense to limit all mercury emission sources, particularly those which are clearly reducible.

Cadmium and Lead Emissions from Waste Incineration

Cadmium and lead emissions from waste incineration in theory are largely preventable using state of the art pollution control systems ie. dry scrubbing with electrostatic precipitators (over 98% removal) and dry scrubbing systems with baghouses (over 99% removal). [19] (See table below) However, the actual removal rates from existing incinerators are not nearly this high. Yost of the Cadmium Zinc Council estimated the average cadmium removal efficiency to be 65% in 1983, and only 75% with improvements. [20] This suggests that cadmium and lead emissions may currently be a problem. We can consider them separately.

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[18] Lindqvist, Oliver, (1987+), Ibid.

[19] Carlsson, Kurt, "Heavy Metals from 'Energy from Waste' Plants -- Comparison of Gas Cleaning Systems", *Waste Management and Research* (1986), 4, pp. 15-20.

[20] Yost, K.J.,*Proceeding from the Fourth International Cadmium Conference* (Munich, West Germany), 1983.

TABLE 7

Emission levels ($\mu g\ m^{-3}$ norm dry gas) and total removal efficiencies (%) for different gas cleaning systems*

	ESP + ESS		ESP + CS		Spray tower + ESP		Dry injection + FF	
Emission	Emission	Removal	Emission	Removal	Emission	Removal	Emission	Removal
Cadmium								
Particulate			30	97	20	98.5	0.04	
Gas							0.1	
Total	40	96					0.14	99.98
Mercury								
Particulate					0		0	
Gas					150	50.0	50	
Total	120	70	50	80			50	85.0
Lead								
Particulates			700	95	240	98.8	10	
Gas							2	
Total	900	95					12	99.9
Zinc								
Particulates			2000	96	1300	98.3	75	
Gas							15	
Total	1800	96					90	99.8
Dust	34000		35000	99.1	< 25000	99.5	< 20000	99.5

*ESP, electrostatic precipitator; ESS, electrostatic scrubber; CS, scrubber with condensation; FF, fabric filter.

Cadmium

Cadmium is not as closely monitored by the EPA as lead, however the EPA has occasionally assessed the annual emissions of major cadmium emission sources. A summary published in the Federal Register in 1985 indicates that fossil fuel combustion was responsible for over 70% of the cadmium emissions from major sources, with municipal waste incineration coming in second with close to 13%. [22] However, there were only 103 municipal waste incinerator sources, while there were well over 1,000 major fossil fuel sources. This suggests that waste incineration represents a more concentrated source of cadmium emissions than fossil fuel sources.

But what risk does exposure to cadmium in the concentrations observed around incinerators pose? The EPA estimated the cancer risk from direct inhalation of cadmium to populations within 50 kilometers of existing municipal waste combustors to be an 0.2 additional cancer cases per year from cadmium alone, and an individual risk range of 10 -4 to 10 -6; for projected municipal waste combustors, they also estimated an extra 0.2 cancer cases caused by cadmium, with an individual risk range of 10 -7 to 10 -6. [23] Thus the risks from cadmium emissions from waste incineration are not huge, but they do contribute to one's overall risk of developing cancer, which is suspected to be cumulative.

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[22] Federal Register, Vol 50, No. 200, Wednesday, October 16, 1985, pp. 42001.

[23] EPA, "Assessment of Health Risks Associated with Municipal Waste Combustion Emissions", in *Municipal Waste Combustion Study* series, 1987.

Lead:

In the late 1970's transportation sources so dominated the field of lead emissions that emissions from other sources seemed almost negligible. However, recent, dramatic reductions in lead emissions from transportation sources have now made it possible to appreciate the importance of other sources of lead emissions, such as solid waste incineration. In 1987, solid waste sources were responsible for 32% of all lead emissions from major sources, second only to transportation which accounted for 37%. [21] To understand the direct risk associated from these emissions, we need to compare the ambient levels resulting from waste incineration to the level deemed "safe" by the EPA. The EPA has done this in a 1988 report entitled "(an) Assessment of Health Risks Associated with Municipal Waste Combustion Emissions." They modeled the ambient lead concentrations resulting from the operation of several different types of municipal waste combustors and found that the maximum modeled concentration of lead ranged from 20% to 60% of the ambient lead standard.

Thus while waste incineration alone may not cause the standard to be exceeded, in combination with other sources (ie.transportation, fuel combustion) waste incineration may significantly contribute to the risk of exposure to hazardous levels of lead.

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[21] EPA, "National Air Quality Emissions Trends Report", 1987.

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[22] Federal Register, Vol 50, No. 200, Wednesday, October 16, 1985, pp. 42001.

[23] EPA, "Assessment of Health Risks Associated with Municipal Waste Combustion Emissions", 1988.

Summary

This chapter outlined the basic problem with mercury, cadmium and lead in municipal waste incinerators:

1) Cadmium and lead in incinerator ash tend to be concentrated on fine particles which are readily inhalable and readily leachable, making the ash, particularly fly ash, hazardous to reuse or dispose.

2) Mercury tends to be released as a vapor phase emission from municipal waste incinerators. Airborne mercury from a number of point sources appears to be responsible for increasing levels of mercury in many lakes. In Sweden, mercury lakes originated from airborne sources has made it hazardous to eat lake fish even in so-called "pristine" regions. To avoid or abate a similar trend in the U.S., we should reduce all reducible emission sources.

3) Waste incineration is a major source of cadmium and lead emissions in the U.S.. Cadmium and lead in incinerators tend to condense on fine particles which are readily inhalable. Cadmium emissions from waste incineration contribute to the risk of developing cancer. Lead emissions from waste incineration alone can raise the ambient concentration of lead to 60% of the lead standard, which does not leave much room for other sources.

Chapter 5:
Options for Management

This chapter describes five basic types of responses to the problem of heavy metals in spent batteries:

1) Waste reduction

1) Toxic use reduction/source substitution

2) Recycling

3) Segregation of batteries and control of disposal

4) Non-segregation and optimization of pollution control in waste management facilities

Waste Reduction

Waste reduction for household batteries would involves the use of longer lasting batteries, or the use of rechargeable batteries, so that fewer batteries would be generated and discarded. In a sense this appears to be happening already: long lasting alkaline batteries are displacing shorter lasting zinc carbon batteries in market share; super long lasting lithium batteries are displacing other types of button batteries for cameras; and rechargeable batteries such as the nickel cadmium and the sealed lead acid batteries are becoming more popular and widely available each year.

One problem with switching to longer lasting battery types is that these longer lasting types happen to contain more hazardous materials than the shorter lasting types. For example, alkaline cells contain more mercury than zinc carbon cells; lithium batteries contain lithium, an explosive material, as a major component; and nickel cadmium and sealed lead acid batteries contain are largely made up of cadmium and lead. If these batteries are used properly, they can replace several shorter lasting batteries and perhaps generate less hazardous waste overall. However if used improperly -- ie. stored on a shelf unused for many years; overcharged; subjected to abuse -- they can end up creating more hazardous waste.

Toxic Use Reduction/Source Substitution

Toxic use reduction appears to be entirely feasible for batteries that use mercury as an antigassing agent: alkaline, zinc carbon, zinc air, and silver oxide cells. European battery manufacturers have reduced the mercury content of alkaline cells from 1% by weight in 1985 to 0.3% in 1988, and they have pledged to reduce down to 0.025% by 1992. [1] They have done this largely in response to proposed and actual restrictions placed on the sale of dry cell batteries by the EC Commission and various European nations. Successes thus far make it seem entirely feasible that the European producers will fulfill their pledge. Perhaps it is time to encourage U. S. producers to follow suit.

A second area for reduction is with mercuric oxide button batteries. The zinc air button battery is a near perfect substitute for the mercuric oxide button battery and it contains less than 3% mercury by weight, versus 35% - 50% mercury by weight for the mercuric oxide battery. While the zinc air battery does not function as well as the mercuric oxide battery under extremes environmental

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1 Europile, Position Paper No. II, 1988.

conditions, it has become quite popular among button battery users and it can be considered a reasonable substitute.

A tricky point with source reduction involves the relationship between source reduction and recycling. If battery manufacturer's eliminate mercury from zinc carbon cells at the same time as the government promotes recycling of mercury from zinc carbon cells, much effort will be wasted and the recycling facilities may become obsolete. It is important to coordinate source reduction and recycling strategies to target some items for reduction, and others for recycling.

Recycling

The greatest success in recycling batteries has been with the lead acid SLI battery used in cars, boats, motorcycles, and other items. Lead acid battery recyclers recycle both the lead and the plastic casings of spent lead acid batteries. While most lead acid automotive batteries do get recycled, the recycling rate has fluctuated widely in recent years, from just over 52% to just over 80% between 1980 and 1986 alone, with recycling rates shadowing the commodity price of lead.

The fluctuation of recycling rates with lead prices points to one of the major difficulties with private sector recycling: the enthusiasm with which the private sector approaches recycling varies according to the price of the recycled commodity. For a hazardous substance such as lead, the market price does not take into account into account the environmental degradation avoided by recycling, nor does it take into account the dollars saved by disposal avoided. For some hazardous materials, environmental degradation may prove to be the most costly component (in terms of spoiled water supplies, contamination of edible fish, long term health care for exposed victims) in the long run. This is why it sometimes makes sense for the government to subsidize recycling of hazardous materials.

For most dry cell batteries recycling is not profitable given current prices and recycling technologies . However, there are some exceptions. At least two private sector companies recycle mercuric oxide and silver oxide button cells in the U.S., and one Swedish company recycles rechargeable nickel cadmium batteries. (see chapter two) The status of battery recycling abroad and the demand for recycling capacity in the U.S. make it seem likely that in the near future it will be possible to recycle at least nickel cadmium, if not other types of dry cell batteries, in the U.S. as well.

A paradox inherent in recovering toxic metals that are valuable from batteries is that batteries that contain the greatest amount of toxic metals in them are those that are most profitable to recover. The argument could be made that the most environmentally benign strategy would be to market batteries containing enough hazardous material to make them easy and economical to recover, for example, the nickel cadmium battery. However, there are some problems with this strategy. First, we know that not all of the batteries will be returned. Second, the recovery process no doubt produced as hazardous waste, and the more material there is, the more the waste. Finally, even if we could get all of the batteries back and if the recovery process was 100% effective, the risks of exposure from production and use might keep us from choosing this option.

Control Disposal

This type of response involves keeping batteries segregated from the municipal waste stream by separate collection or mechanical separation, and doing one of the following:

- landfill in a protected municipal waste landfill rather than incinerate
- monofill in a single purpose landfill
- treat and/or dispose as hazardous waste

For batteries which cannot be recycled at the present time, segregation and control of disposal may be an appropriate short term response, especially in regions that incinerate their wastes. By segregating spent batteries from incinerator bound wastes we can significantly reduce heavy metal emissions and avoid the heavy metal contamination of ash that makes its reuse and disposal hazardous.

Segregating spent batteries from incinerator bound waste has been shown to be quite effective in reducing mercury emissions from incinerators in Sweden. Measurements of mercury emissions at the Hogdalen and Uppsala incinerators in Sweden before and after the implementation of a battery collection program show a decrease in emissions by 58% (Hogdalen, 1982 to 1985) and 60% (Uppsala, 1982 to 1983) after program implementation.[2] Some of these decreases may be due to decreases in the use of mercury in batteries, however keep in mind that the major mercury reductions in the battery industry occurred after 1985.

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[2] Westergard, Bengt, "Mercury from Hogdalen Incineration Plant in Stockholm, 1972 -1985", *Waste Management and Research* (1986) 4, p. 21; and Backman, Michael and A. Papageorgiou, "Collection of Batteries", Swedish National Board for Technical Development, 1984.

Battery collection programs in incinerator regions in the U.S. are faced with a dismal set of alternatives for managing dry cell batteries once they are collected. The majority of dry cell batteries are not recyclable in the U.S.. This means that they either must be stored for future recycling, disposed in a landfill , or disposed as hazardous waste. In most cases, batteries collected in local collection programs are disposed as hazardous wastes. This raises a number of important considerations:

1) Is this a wise use of scarce hazardous waste disposal space? Data presented in this thesis on risks from landfilling spent batteries suggests that heavy metals in spent batteries are not highly mobile, at least in the short term. Perhaps keeping spent batteries in lined landfills with leachate collection systems is enough protection.

2) Is this a wise way to manage the resources potentially available in spent batteries? If spent batteries are codisposed with hazardous wastes in hazardous waste landfills, it is unlikely that they will ever be retrieved for recycling. However if they are disposed in a battery monofill or in a carefully mapped out section of a municipal waste landfill, it might be possible to recover them for future recycling.

3) Is this an equitable way to manage waste? By segregating spent batteries from one waste stream and shunting them into another, we shift the risk of exposure to heavy metals from one place to another and from the short term to the long term. Unless we recycle batteries or immobilize them permanently, we have done little to reduce overall risk.

The Swedish government has dealt with these issues by storing, rather than disposing, spent batteries collected from incinerator bound waste. They have designed special containers to keep batteries intact during storage, and they are actively researching ways to recycle the stored batteries.

Improve Pollution Control Systems in Waste Management Facilities

The current regulatory requirements for municipal waste incinerators and the proposed regulations for municipal waste landfills do not require new facilities to employ the most protective pollution control systems available for ensuring against exposure to heavy metals in batteries. A more stringent set of regulations could require that:

1) All new landfills have liners, groundwater monitoring systems,and/or leachate collection systems, and

2) All new incinerators employ a spray-tower and baghouse emission control system, or any other combination that achieves at least the same removal efficiency for mercury (85%), cadmium (over 99%) and lead (over 99%). (See chapter on incineration risks for sources).

One problem with relying on pollution control equipment alone to control heavy metal releases from landfills and incinerators is that these systems may break down. For landfills, liners can form leaks, and if they do and there is no leachate collection system, then what? For incinerators, emission control systems may lose their effectiveness over time; this needs to be carefully monitored.

Another problem is what to do with the hazardous residues of these systems? As with any"end of pipe" type of control, requiring more the effective pollution capture does not eliminate risk; it merely shifts it from medium to medium (ie. air to solid waste), site to site (ie. communities near solid waste management facilities to communities near hazardous waste management facilities), and short term to long term.

The bottom line with improved pollution control is, why rely on this alone when there are better long term solutions?

Chapter 6:
Proposal for Implementation

With a multitude of battery types on the market there is no single option for spent battery management that works best for all types of batteries. A policy that emphasizes substitution away from the use of the hazardous metals where feasible and recycling of those materials which cannot be reduced in the foreseeable future offers the greatest hope for the safe, sustainable use of batteries in the middle to long term, but in the shorter term it may be necessary to supplement such a policy with measures aimed at controlling short term releases of toxic materials in batteries from waste management facilities, particularly incinerators.

In this chapter I outline an implementation strategy which encompasses all three: reduction, recycling, and control.

1) Phase out the use of mercury in batteries

Battery manufacturers in the U.S. and abroad have achieved significant reductions in the use of mercury as an antigassing agent, and some of the most progressive manufacturers have sought to eliminate mercury altogether from some types of batteries. While some of the more forward-looking companies have set voluntary goals for future mercury reductions, not all have followed suit and it seems apparent that some sort of government persuasion is required.

The European battery manufacturer's association made a voluntarily pledge to reduce mercury the content in alkaline cells drastically within the next few years, largely in response to the threat of legislation by European countries to ban the sale of batteries containing more than trace amounts of mercury. In the U.S. we could command the battery manufacturers to stop using mercury as an antigassing agent in batteries by banning the sale of batteries with more than threshold amounts of mercury in them under the Consumer Product Safety Act, but this would likely provoke strong resistance from the battery manufacturing industry, and time and money that could be spent on research would instead be spent in court and on lawyers fees. A better approach would be to work with the battery industry to negotiate a time table for reductions which takes into account the industry's perspective on what is feasible. At a minimum, the U.S. battery industry should be able to agree to the same reductions that the European industry has promised.

The other area for source reduction is with mercuric oxide button batteries. The zinc air button battery,which contains about 1% mercury by weight, serves as a reasonable substitute for the mercuric oxide button battery, which contains about 35% - 50% mercury by weight. European battery manufacturers have agreed to phase out mercuric oxide button batteries over time. The Consumer Product Safety Commission should negotiate with the U.S. battery manufacturers to work out a schedule for phasing out mercuric oxide button cells in the U.S. as well.

2) Promote the Use and Recycling of Rechargeable Batteries

In the past, the U.S. private sector has not been interested in recycling most types of consumer dry cells because the recovered materials do not bring high enough returns to offset the costs of battery transportation, materials recovery, and disposal of hazardous byproducts. With government incentives or start-up funding, it is possible that the private sector will take some initiative in developing new and innovative recycling technologies for batteries.

I propose that government funding be concentrated on developing recycling capacity for rechargeable nickel cadmium batteries first, and perhaps other types of batteries later. The Swedish success in recycling nickel and cadmium from consumer nickel cadmium batteries attests to the fact that nickel cadmium battery recycling is not only feasible, but perhaps even profitable. Along with this effort, the government should promote the use of nickel cadmium rechargeable batteries. By promoting the use of rechargeable batteries, fewer batteries will be generated, which means less transportation and handling costs for any type of battery program. Furthermore, nickel cadmium batteries are cheaper to use than other types of batteries when used properly; education may be enough to sway citizens to purchase the more expensive to buy, but cheaper to use, battery. Last but not least, since cadmium is mined as a byproduct of zinc, the supply of cadmium will continue to be available even if nickel cadmium batteries are eliminated. If the cadmium is not used in batteries, it may end up being used in other consumer products that enter the waste stream. It makes more sense to use it in batteries and recycle it, rather than to use it in paints or other consumer products that may be disposed.

In addition, recycling of lead acid automotive type batteries needs to be promoted at all times. I recommend that the Battery Council International Model Battery Legislation be adopted by the federal government. This legislation prohibits the landfilling of wet cell lead acid batteries and requires wet cell lead acid retailers to accept spent lead acid batteries and to post signs informing consumers of their recyclability.

3) Control releases of heavy metals from waste management facilities.

Landfills:

It seems from the limited data presented here that heavy metals in batteries disposed at the current rate in landfills are not likely to be released in hazardous quantities over the short term. However we don't have evidence to indicate that heavy metals from batteries will stay put in landfills over the long term. Given that we don't know the long term behavior of heavy metals in landfills, it makes sense to at least monitor the concentration of heavy metals in landfill leachate tests, and to require new landfills to be equipped with liners and leachate collection systems.

Incinerators:

Source reduction and recycling of heavy metals in batteries will reduce heavy metal emissions and heavy metals in ash over the longer term, however the risk of exposure to airborne metals and the ash management problems caused by cadmium and lead in batteries are great enough in the short term to demand interim protection. We need to minimize heavy metal emissions and heavy metals in ash by collecting batteries prior to incineration, and by employing the most effective pollution control systems available for reducing heavy metal emissions.

Separation of batteries prior to incineration and collection of recyclable batteries are probably best planned and managed at the local level, where they can be worked into a curbside collection or voluntary dropoff program. While technologies to mechanically separate non-combustible materials from mixed waste are available and have been effective at reducing heavy metal emissions and heavy metals in ash, the mixed pot of non-combustible materials does not pave the way for future recycling of materials in spent batteries. A curbside collection or voluntary dropoff program has the advantages of providing good raw material for potential recyclers and also of getting people into the habit of thinking of batteries as a special type of waste. This may come in handy if recycling of batteries catches on.

On the issue of pollution control, it appears to be technically feasible to dramatically reduce mercury emission from municipal waste incinerators by employing a spray dryer plus a baghouse system. . The Federal EPA should revise its standards for new incinerators (ie. New Source Performance Standards under the Clean Air Act) to take into account the state-of-the-art for mercury control. Regardless of whether the EPA takes action, states should control mercury releases from incinerators by including stringent performance standards for mercury removal in permits for new incinerators.

Funding:

A federal tax similar to the environmental tax imposed on batteries in Sweden would be ideal for raising the funds to support battery recycling efforts and education programs.

Summary

The overall policy described in this chapter has seven major components:

1) Negotiate or legislate a timetable to reduce or eliminate the use of mercury in batteries that use mercury as an antigassing agent (ie. zinc carbon, alkaline, zinc air, zinc silver).

2) Phase out production of consumer mercuric oxide button cells in favor of zinc air button cells.

3) Promote the use of rechargeable batteries through education.

4) Charge a fee on batteries to raise funds to a) promote the development of recycling technologies in the U.S. for consumer dry cells and b) subsidize recycling of lead acid batteries and consumer dry cells when the price of recovered materials falls below the break even price c) conduct information campaigns.

5) Keep spent batteries out of incinerators in order to a) keep heavy metal emissions down b) avoid contaminating incinerator ash with metals that make it hazardous to dispose and which preclude the possibility of ash reutilization.

6) Require landfills and incinerators to utilize pollution control systems that protect against both short and long term releases of heavy metals in spent batteries.