Health Consultation

DRUM-TOP BULB CRUSHER DEMONSTRATION
AT THE MINNEAPOLIS-ST. PAUL INTERNATIONAL AIRPORT

BLOOMINGTON, HENNEPIN COUNTY, MINNESOTA

DECEMBER 1, 2003

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Agency for Toxic Substances and Disease Registry
Division of Health Assessment and Consultation
Atlanta, Georgia 30333

Health Consultation: A Note of Explanation

An ATSDR health consultation is a verbal or written response from ATSDR to a specific request for information about health risks related to a specific site, a chemical release, or the presence of hazardous material. In order to prevent or mitigate exposures, a consultation may lead to specific actions, such as restricting use of or replacing water supplies; intensifying environmental sampling; restricting site access; or removing the contaminated material.

In addition, consultations may recommend additional public health actions, such as conducting health surveillance activities to evaluate exposure or trends in adverse health outcomes; conducting biological indicators of exposure studies to assess exposure; and providing health education for health care providers and community members. This concludes the health consultation process for this site, unless additional information is obtained by ATSDR which, in the Agency's opinion, indicates a need to revise or append the conclusions previously issued.

You May Contact ATSDR TOLL FREE at
1-888-42ATSDR
or
Visit our Home Page at: http://www.atsdr.cdc.gov

HEALTH CONSULTATION

DRUM-TOP BULB CRUSHER DEMONSTRATION AT THE MINNEAPOLIS-ST. PAUL INTERNATIONAL AIRPORT

BLOOMINGTON, HENNEPIN COUNTY, MINNESOTA

Prepared by:

Minnesota Department of Health
Under a Cooperative Agreement with the
Agency for Toxic Substances and Disease Registry

Foreword

This document summarizes public health issues related to levels of mercury emitted from a fluorescent bulb recycling system considered for use at a Minnesota company. It is based on a formal evaluation prepared by the Minnesota Department of Health (MDH). A number of steps are necessary to do such an evaluation:

- **Evaluating exposure:** MDH scientists begin by reviewing available information about environmental conditions at the site. The first task is to gather information on emissions from an operation or facility and how people might be exposed to these emissions. Usually, MDH does not collect its own environmental sampling data. We rely on information provided by the Minnesota Pollution Control Agency (MPCA), U.S. Environmental Protection Agency (EPA), and other government agencies, businesses, and the general public.
- **Evaluating health effects:** If there is evidence that people are being exposed—or could be exposed—to hazardous substances, MDH scientists will take steps to determine whether that exposure could be harmful to human health. The report focuses on public health—the health impact on the community as a whole—and is based on existing scientific information.
- **Developing recommendations:** In the evaluation report, MDH outlines its conclusions regarding any potential health concern posed by facility emissions. It also offers recommendations for reducing or eliminating human exposure to emitted pollutants. The role of MDH in dealing with industrial emissions is primarily advisory. For that reason, the evaluation report will typically recommend actions to be taken by other agencies—including EPA and MPCA. However, if there is an immediate health threat, MDH will issue a public health advisory warning people of the danger and will work to resolve the problem.
- **Soliciting community input:** The evaluation process is interactive. MDH starts by soliciting and evaluating information from various government agencies, the company responsible for the emissions, and the community surrounding the facility. Any conclusions about the facility are shared with the groups and organizations that provided the information. Once an evaluation report has been prepared, MDH seeks feedback from the public.

A health consultation is a working document. It describes site conditions using data available at a specific time. If more data become available, MDH can write follow-up documents to describe newly available data, information, or changing conditions.

If you have questions or comments about this report, we encourage you to contact us.

Please write to: Community Relations Coordinator
Site Assessment and Consultation Unit
Minnesota Department of Health
121 East Seventh Place/Suite 220
St. Paul, MN 55101

Or call us at: (612) 215-0916 ***or*** 1-800-657-3908
(toll-free call—press "4" on your touch tone phone)

General information available at:
http://www.health.state.mn.us/divs/eh/hazardous/index.html

Introduction

Mercury emissions are a public health concern because mercury vapor is very toxic. Emitted mercury can be deposited locally, regionally, or worldwide. It can be washed into surface waters and converted to methylmercury that accumulates in aquatic food chains. People ingest methylmercury in fish, especially predatory fish at the top of aquatic food chains. Therefore, health and environmental agencies generally support best possible controls on mercury emissions.

Fluorescent light bulbs contain small amounts of mercury, ranging from 8 to 50 milligrams per bulb. When they are broken, a significant proportion of the mercury in fluorescent light bulbs is released into the air as mercury vapor. This mercury vapor can be hazardous to individuals exposed when the lamp breaks. The mercury vapor can also contribute to circulating atmospheric mercury. Atmospheric mercury is the primary source of mercury that eventually accumulates in fish. As a result, the U.S. Environmental Protection Agency (EPA) recommends that mercury in fluorescent bulbs be recycled. The Minnesota legislature enacted disposal bans on fluorescent light bulbs effective August 1, 1993 for businesses and August 1, 1994 for households (Minnesota Statutes 115A.932).

Fluorescent bulbs, in Minnesota, can be managed as hazardous wastes or they can be recycled. Given the costs associated with disposing of hazardous waste, businesses generally recycle fluorescent bulbs. Residential users can also recycle fluorescent bulbs through collection facilities. The bulbs are packaged and shipped to a few recycling centers, located in the Twin Cities area or out of state. Breakage during storing and shipping can result in unintentional releases. However, storing and shipping bulbs inside of plastic bags can decrease the amount of mercury that can escape if bulbs are accidentally broken. Because storage and shipping costs can be high because of the size of fluorescent bulbs, some large businesses have expressed interest in crushing bulbs onsite as part of a recycling program.

The purpose of this health consult is multifold. First, a neighboring state, an airline company and the Minnesota Pollution Control Agency (MPCA) requested a prudent review to determine what health concerns, if any could be associated with this fluorescent bulb crushing process. Secondly, this health consult is intended to support and as a reference for the MPCA's recent policy on this type of bulb crushing device.

Background Discussion - Fluorescent lightbulbs and mercury emissions

A typical 4-foot fluorescent light bulb contains between 8 and 50 mg of mercury (in year 1990 - 50 mg Hg/unit; in year 2000 - 13 mg Hg/unit; in year 2005 (projected) - 8 mg Hg/unit; (MPCA, 2001). Recently manufactured fluorescent light bulbs generally have less mercury than older bulbs. When broken, fluorescent bulbs can be expected to release about 20 - 40% of their mercury to the atmosphere in 2 weeks following breakage, with about 1/3 of that emitted during the first 8 hours (Aucott et al., 2003). If the bulb fragments, including phosphorus powders in the fragments are incinerated, all of the mercury in a bulb will likely volatilize. Nationwide, it is assumed that only about 15% of fluorescent bulbs were recycled in 1999 (NEMA, 2000). Nationally, most are probably

tossed in dumpsters and incinerated or dumped, broken, into landfills. In Minnesota, the percent recycled is probably considerably above estimates for the US, because it is illegal in Minnesota to put fluorescent lightbulbs in the trash. A study commissioned by the MPCA (MPCA, 2001) assumed that about 30% of discarded fluorescent bulbs in Minnesota were recycled in 2000, and it projected that about 50% of all mercury-containing bulbs will be recycled in 2005. Estimating mercury emissions from recycling facilities is problematic because mass balance data are not available. In addition, standard methods for mercury recycling operations have not been adopted.

It is estimated that there are about 100 tons of mercury in fluorescent bulbs in use in the US (Minnesota Office of Environmental Assistance, 2003). About 1.5 tons per year (t/yr) mercury is emitted from broken lamps (primarily fluorescent) in the US (EPA, 1997). This amounts to about 1% of the total US mercury emissions. (There appears to be agreement that this estimate is low, but it remains the best available estimate (MN OEA, 2003)). Therefore, while control of mercury emissions from fluorescent lightbulbs is an indoor air concern and a local concern near disposal or recycling facilities, lightbulbs are a relatively small, but controllable, contributor to regional and global pollution. As a result, health concern about exposure to mercury from fluorescent lights is primarily a concern about indoor air exposure to mercury and about the potential for facility and local contamination from mercury - either directly from mercury in the air, or from improper handling of fluorescent bulb waste.

The largest source of mercury emissions in the US are combustion point sources (86.9%), with coal-fired power plants (32.6%) the largest contributors (EPA, 1997). Power plants typically broadcast emissions into the atmosphere from tall stacks. This increases the dilution of emissions and decreases local exposure. However, mercury from these facilities is eventually deposited on land or water. Once it is washed into a watershed or ocean, it can be converted to methylmercury and incorporated into aquatic food chains. As a result fish, especially high trophic level predators, can have significant levels of mercury (as methylmercury) in their muscle tissue. Fish consumption is likely, the largest source of mercury for most Americans.

Fluorescent lightbulbs are about 4 times as efficient as incandescent lightbulbs (Moore et al., 1996; Energy Star) and work for an average of 20,000 hours (see (EPA, 1997) for review). As a result over their lifetime, a 40-watt fluorescent bulb may use about 2,400,000 watt-hours less than incandescent bulbs providing similar light. A kilogram (kg) of coal produces about 2,860 watt-hours of electricity (Moore et al., 1996). Therefore, use of a fluorescent bulb requires about 840 kg less coal than similar incandescent bulbs. Coal used in the US contains about 0.1 ppm mercury (MPCA, 2000), about 50% of mercury emissions are captured with emission controls on coal-fired power plants (see (EPA, 1997) for review), and about 50% of electrical power in the US is from coal. This suggests that about 21 mg mercury is released to the atmosphere when powering a single 40-watt fluorescent bulb over its lifetime, and about 84 mg mercury is emitted from power plants when incandescent bulbs are used to achieve similar lighting.

Bulb manufacturers and electric utilities have stated that decreased energy use from utilization of fluorescent bulbs may not cause a proportional decrease in coal use. This is because small changes in electrical needs during daytime hours (hours of highest fluorescent bulb use) may be met predominantly by gas and oil-fired generation units (EPA, 1998). In a report on fluorescent bulbs(EPA, 1998), the EPA concluded that mercury reduction from the use of fluorescent lamps can only be achieved if bulb breakage is limited, or if emissions caused by breakage are controlled.

"Bulb Eater" Demonstration

On February 7, 2002, representatives of the Minnesota Pollution Control Agency (MPCA), Minnesota Department of Health (MDH), Hennepin and Ramsey County Hazardous Waste, and other hazardous waste officials attended a demonstration of a "Bulb Eater" (Air Cycle Corporation, Broadview IL; Model 55 VRS) drum-top fluorescent lamp crusher at an airport facility in Bloomington, Minnesota. The "Bulb Eater" is a crusher and vacuum unit (rated at 40 cubic feet per minute [cfm]) mounted on a replaceable 55-gallon drum. A 2-foot extension tube, into which fluorescent bulbs are inserted, extends vertically from the unit. With the unit turned on, fluorescent bulbs fed into the vertical tube are sucked into the drum and crushed by a spinning chain. The vacuum is exhausted through a particulate filter, a "dual action" HEPA filter, and lastly, an activated charcoal filter. About 1,350 T8, 4-foot, 1-inch diameter bulbs fill a 55-gallon drum. When the drum is full, the vacuum unit can be removed and attached to another drum. The full 55-gallon drum is then sealed and shipped to a hazardous waste facility. The manufacturer of the "Bulb Eater" (Air Cycle Corporation) recommends replacement of the particulate filter with every drum and replacement of the HEPA every 10 drums. Air Cycle advertises that the activated charcoal filters remains effective for about 1 million bulbs (about 1,000 drums).

The company that demonstrated the "Bulb Eater" is one of the largest employers in Minnesota. The company recycles about 30,000 fluorescent bulbs a year (most from their facilities in the Twin Cities area). The demonstration "Bulb Eater" was stored and used in a large room that was apparently used for storage and may have contained machinery that was used in place. In addition, there appeared to be considerable employee traffic and reasonably high air flow through the room. One of the adjoining rooms was a break or lunch room. MPCA staff used a Lumex RA-915+ analyzer to measure mercury concentrations in exhaust air and in breathing. The range of detection for the Lumex is about 1 nanogram per cubic meter (ng/m^3) to about 50,000 ng/m^3.MDH considers the quantitation range of the Lumex to be between about 10 ng/m^3 and 50,000 ng/m^3. At readings above this, instrument responsiveness may flatten out (decrease) leading to potential underestimation of actual concentrations. Data were recorded automatically as averages of thirty 1-second measurements, with relative standard deviations (%) based on the 30 data points (see Table 1).

Table 1. Representative Data From Lumex RA-915+ Analyzer Measurements of Exhaust Air During February 7, 2002 Demonstration of "Bulb Eater" Drum-Top Fluorescent Bulb Crusher in Bloomington, Minnesota.

Time (AM)	Location, Activity	Mercury (ng/m^3)	Relative standard deviation (%)
10:18	Conference room	5	46
10:19		5	20
10:20		5	16
11:37	Room where bulb eater located (doors to room closed)	14	10
11:38		14	1
11:39		13	5
11:40	Turn on empty bulb eater; monitor at exhaust from machine	79	102
11:41		51	3
11:42		76	56
11:43		34	72
11:44		51	130
11:47	Start feeding used 4-foot T8 fluorescent bulbs; monitor at exhaust from machine	22,360	109
11:48		51,060	9
11:48		43,630	45
11:49		52,010	16
11:50		44,210	16
11:51	Monitor breathing height (5 feet off floor, near machine)	48,800	14
11:51		35,080	20
11:52		31,460	17
11:53	Door opened	20,310	144
11:54		2,672	23
11:54		6,966	69
11:55	Stopped feeding bulbs	2,335	28
11:56		1,817	28
11:58		2,161	110
11:59	Monitor at exhaust from machine	26,380	43
Noon		30,910	30

The data collected at the machine exhaust during crushing of 4-foot T8 bulbs show an air concentration of about 50 micrograms per cubic meter ($\mu g/m^3$). Mercury concentrations at breathing height near the crusher are 60%–90% of the exhaust air concentrations. The measured mercury vapor concentration decreased noticeably when a door to the room remained open during measurements.

Sufficient data are not available to conduct an analysis of the percent mercury emitted or a mass balance of mercury. However, at an exhaust rate of 40 cfm (Air Cycle Corporation, 2002) the bulb crusher discharged about 56 µg per minute (µg/min) while crushing fluorescent bulbs.

Mercury Health Effects and Criteria

Following the demonstration, MDH presented attendees with information about the derivation and application of health-based criteria or reference values for mercury (see Attachments 1 and 2).

Even though total emissions to the atmosphere drive the interest in recycling fluorescent lamps, it is not the main health concern related to the use of drum-top bulb crushers. The contribution of mercury from broken fluorescent bulbs to atmospheric mercury, to mercury deposited from the atmosphere, and to methylmercury accumulation in the food chain, is small (about 2% of the total Minnesota emissions) compared to major sources such as coal combustion. (For information on methylmercury and exposure to methylmercury in the food chain, consult the MDH Fish Consumption Advisory website at: http://www.health.state.mn.us/divs/eh/fish/index.html) On the other hand, the potential for hazardous *mercury vapor* exposure near a bulb recycling system or facility may be quite large. Therefore, standards and health-based reference values for mercury vapor exposure are reviewed below.

Individuals with an expectation of on-the-job exposure to mercury are covered by exposure regulations enforced by the Minnesota Occupational Safety and Health Agency (MN OSHA) or U.S. Occupational Safety and Health Administration (OSHA) regulations. These values are not considered to be protective for the general population. The MN OSHA maximum time-weighted average (TWA) exposure for mercury vapor is 50,000 ng/m^3. This value supersedes the OSHA TWA of 100,000 ng/m^3. MDH recommends safe exposure levels for the general public and individuals with no expectation of workplace exposure. MDH uses health-based reference values from different organizations based on availability. MDH uses health-based numbers in the following preferential order: proposed MDH Health Risk Values (HRVs), EPA Integrated Risk Information System (IRIS) reference concentrations (RfCs), and provisional RfCs and other health-based values, such as California Reference Exposure Levels (RELs) and Agency for Toxic Substances and Disease Registry (ATSDR) Minimum Risk Levels (MRLs).

There are no MDH HRVs for elemental mercury, therefore, MDH relies on health criteria or standards calculated by other agencies.

Chronic Exposure Reference Values: Mercury (Elemental)

EPA's integrated risk information system (IRIS) database specifies an RfC for chronic exposure to mercury vapor of 300 ng/m^3 (EPA IRIS, 2003). An RfC is an exposure concentration that is not expected to result in adverse health effects in most people, including sensitive subpopulations, exposed over a lifetime. The mercury RfC is derived from multiple studies of occupational exposures. Most studies were conducted with employees in chlor-alkali plants who were exposed to mercury vapor. The observed critical effects included hand tremors, increases in memory disturbances, and slight subjective and objective evidence of autonomic nervous system dysfunction. The lowest observable adverse effects concentration (LOAEC) in the occupational studies converge at 25 µg/m^3. Affected workers had mean whole blood mercury concentrations of 10–12

micrograms per liter (µg/L). Adjusted to a 24 hour, 7 days per week exposure, the $LOAEC_{adj}$ = 9.0 µg/m^3. An uncertainty factor of 30 was applied to the $LOAEC_{adj}$ to arrive at an RfC that is assumed to engender no adverse effects (see Attachment 2). The uncertainty factor includes a factor of 10 for human variation in sensitivity, and a factor of 3 for lack of studies on the reproductive and developmental effects of elemental mercury.

The calculation of this RfC assumes that there is a threshold level for effects. A threshold for toxicity from mercury vapor exposure is presumed in the standard model used by EPA for noncarcinogens.

The California Office of Environmental Health Hazard Assessment (CA OEHHA) derived its Reference Exposure Level (REL) for chronic inhalation exposure to mercury from the same studies used to develop the IRIS RfC. However, instead of using the cumulative uncertainty factor of 30 used by EPA, CA OEHHA has adopted an uncertainty factor of 100. This is based on a factor of 10 for the uncertainty of using an LOAEC exposure instead of a "no observable adverse effects concentration" (NOAEC) when calculating the REL. It also includes a factor of 10 for human intraspecies variability (see Attachment 2). The California REL for mercury (elemental and inorganic) is 90 ng/m^3 (CA OEHHA, 2001).

The Agency for Toxic Substances and Disease Registry (ATSDR) has a health-based minimum risk level (MRL) for mercury of 200 ng/m^3 (ATSDR, 1999). This MRL is calculated from the same data that was used to calculate the IRIS RfC. However, the MRL calculation assumes that in an occupational exposure, one third of the daily inhaled air each working day is contaminated. The RfC assumes that half of the working daily inhalation is contaminated (see Attachment 2).

MDH uses IRIS RfCs for giving exposure advice when there is not an HRV. MDH has some concern that the EPA RfC uncertainty factor of 30 may not sufficiently protect sensitive subpopulations given that the basis of the underlying value is an LOAEC. The California chronic mercury REL does provide this additional protection. However, practical application of the mercury REL at contaminated sites may be problematic because personal exposure to mercury from other sources, including dental amalgams, may be in the range of the REL. MDH therefore recommends that the EPA criterion be used, but that care be taken to ensure that chronic exposures to mercury from all sources do not exceed this level.

Acute Exposure Values: Mercury

California OEHHA developed an acute REL for mercury vapor based on developmental effects in the offspring of exposed rats. Central nervous system effects in pups were noted following exposure of dams to 1.8 mg/m^3 for 1 hour/day during gestation. A cumulative uncertainty factor of 1,000 is attached to this REL because it is based on an LOAEL (10x), the primary study was an animal study (10x), and human response to all chemicals is variable (10x) (see Attachment 2).

The CA OEHHA acute REL for mercury vapor is 1,800 ng/m^3, with a critical endpoint of reproductive or developmental effects (CA OEHHA, 2001).

Discussion—"Bulb Eater" Demonstration

Data from the "Bulb Eater" demonstration show that the operator and others nearby can be exposed to mercury vapor concentrations that exceed acute exposure levels recommended by MDH. In addition, the measured mercury concentrations in breathing space approached the Minnesota OSHA TWA (8 hour) limit of 50,000 ng/m^3. Because crushing operations are not typically conducted for a full 8-hour day, it is unlikely that anyone would be exposed to levels above the TWA at this facility. While the operator of the equipment may be covered by OSHA standards, nearby workers likely do not expect to be exposed to mercury as part of their job. Therefore, these employees should not be exposed to mercury vapor concentrations that exceed 1,800 ng/m^3 for acute exposures, or 300 ng/m^3 for chronic exposure durations.

Note that data suggests that an individual working near the "Bulb Eater" at this facility may be exposed to about 20 times the acute REL for mercury (i.e. 35,000 ng/m^3). In addition, assuming 1-hour use per day, 5 days a week, an individual may be exposed to an (adjusted) longterm average of 1,000 ng/m^3. That is more than 3 times the chronic RfC and within a factor of 10 of a concentration where adverse effects have been observed. This calculation may underestimate exposure; it assumes direct exposure only, and no exposure to residual mercury that accumulates in the room or building.

The room where the "Bulb Eater" was operated during the demonstration was a very large room with a high ceiling and, apparently, good air circulation. If similar bulb-crushing equipment is used in a smaller room, with less air circulation, mercury concentrations probably would be significantly higher than those measured during the demonstration. Therefore, the use of the "Bulb Eater" in other locations or at other businesses could lead to significantly higher exposures to mercury vapor. Sensitive populations, such as small children and fetuses (through their mothers), could also be at risk. Adverse health effects may occur in such individuals exposed to similar, or much lower concentrations than those measured during the "Bulb Eater" demonstration (i.e. greater than 1,800 ng/m^3 for a short period). If exposure concentrations, frequency of exposure, or duration of exposure are increased, the severity of effects may also increase.

Mercury exposure likely depends on the following factors:

- number of bulbs crushed,
- the amount of time the machine operates,
- ventilation in the area where the crusher is used,
- proximity of people to the operation, and
- possibly, crusher storage location.

While the magnitude and extent of mercury exposure will vary from location to location, it is clear that excessive exposures to mercury can occur.

Filled drums of crushed fluorescent bulbs are expected to contain about 10 grams of mercury. This is a considerable amount of hazardous material. Implicit in an analysis of this demonstration is that the business that operates the drum-top crusher properly maintains the system. Filled 55-gallon drums of crushed fluorescent bulbs also must be handled and disposed as hazardous waste. Without specific regulation of the use and maintenance of drum-top crushers there is considerable opportunity for abuse. Failure to treat drum-top bulb crushers as systems that generate hazardous wastes could lead to additional mercury vapor exposures and additional mercury releases into the environment.

Only a single design of a drum-top bulb crusher was demonstrated in February 2002. Other designs may emit more or less mercury. There appeared to be a number of design improvements that could be made that would result in significant reductions in mercury emissions. Vacuum is created in the bulb crusher to draw each bulb into the drum and to maintain a negative air pressure inside the apparatus as it crushes bulbs. About 40 cfm were exhausted from the demonstrated drum-top crusher while it was in use. When crushed, the bulbs themselves implode because of negative pressure inside fluorescent bulbs. If a vacuum was created in the drum-top crusher only momentarily, to suck in the bulbs, the amount of air exhausted could be dropped to a fraction of the current exhaust. This could decrease mercury emissions significantly. In addition, it might be possible to design more effective mercury vapor filters for drum-top crushers. Filters that react chemically with mercury (amalgamating filters) or filters made of materials that mercury can stick to, such as zeolites, are possibilities.

Regulatory Response to Drum-Top Bulb Crusher Demonstration

The EPA report (EPA, 1998) stated that in previous demonstrations of drum-top bulb crushers, “leaks at the seal between the drum and the crusher have been responsible for violations of the OSHA mercury standard.” EPA also indicated that the efficiency and useful life of charcoal filters in drum-top crushers are not well characterized. The report concluded that “overall, there is little basis for assigning a control efficiency to drumtop crushers equipped with controls... On-site crushing by lamp generators is officially prohibited under the UW [Universal Waste] standards, as promulgated by the Agency.”

On March 13, 2002, MPCA informed Air Cycle Corporation that “MPCA would not allow the use of drum-top crushers at this time nor could it commit to collecting and compiling the necessary data to complete the evaluation properly at this time” (Attachment 3; (MPCA, 2002). In a subsequent action, MPCA in consultation with MDH and the Minnesota Office of Environmental Assistance (MOEA), submitted a letter offering cause for opposing the “immediate final approval” of Virginia’s State Hazardous Waste Program accepting the use of drum-top crushers for hazardous waste lamps, published at 68 FR 11981-11986 and 68 FR 12015 (March 13, 2003). A copy of this letter from the MPCA to the EPA is also attached to this consultation (Attachment 4; (MPCA, 2003).

In the April 14, 2003 letter, MPCA encouraged EPA to undertake policymaking on drum-top lamp crushing, including a full discussion of the relevant issues and a

review of data obtained from ongoing equipment testing. "Because mercury is a pollutant that knows no geographic boundaries, states and regions should not be making their own regulations to address drum top lamp crushers without input from other states, regions and EPA headquarters. Policies and regulations should be discussed and established through a national dialogue that takes these and other issues into account."

In addition, MPCA requested that EPA review and respond to a number of issues, including the following:

- What impact can crushing have on the total mercury emissions? Could this affect overall mercury reduction strategies?
- Is a healthy male adult worker standard appropriate for a contaminant like mercury?
- Should operating conditions at bulb crushing operations require segregated air flow?
- Should lamp crushing be allowed at any generator location, as a "low risk" activity, or should it be allowed only at facilities with certain operational capabilities and/or hazardous waste large quantity generator (LQG) status?
- Should ubiquitous crushing operations be monitored, limited, or prohibited?
- What type of regulatory program can be effectively and consistently implemented and enforced with the current resource constraints faced by most state and local governments?
- What are the appropriate legal and contractual responsibilities of the fluorescent lamp crusher equipment vendors with regard to ensuring proper use and maintenance of the equipment?
- How could equipment vendors and crusher operators regulate themselves?
- How could EPA and the states regulate the "quick-buck" lamp crushers likely to flood the market, but unlikely to contain the mercury?

Children's and Special Health Considerations

EPA RfCs are developed to be protective of sensitive individuals and children. Children and fetuses have been shown to be sensitive to some mercuric compounds, including methylmercury (EPA, 2001). Increased sensitivity to elemental mercury has not been studied closely. MDH believes that the uncertainty factors recommended by EPA for chronic exposure (30) and CA OEHHA for acute exposures (1,000) are justified. It is unlikely that a child could be exposed to the high concentrations associated with the use of drum-top bulb crushers. Pregnant women, however, may be unknowingly exposed at their workplace. If the technology is used at other locations, site specific considerations could result in a different outcome.

In general, MDH recommends minimizing exposure of children and women of child-bearing age to any significant source of mercury vapor. Those sources include broken fluorescent bulbs and other broken mercury-containing devices, such as thermometers, barometers, switches, thermostats, and sphygmomanometers (blood pressure cuffs).

Summary and Conclusions

MDH and other state, county, and local agencies attended a demonstration of a drum-top bulb crusher ("Bulb Eater") at a very large business in the Twin Cities area. The drum-top crusher was stored and used in a large room with significant employee traffic. The room was also located next to a lunch or break room. During operation of the bulb crusher, mercury vapor concentrations in the breathing air approached MN OSHA (8 hour) limits. The measured concentrations were about 25 times greater than an acute health-based criterion for the general public.

MDH and MPCA reviewed the data acquired during this demonstration. They determined that the use and proliferation of drum-top bulb crushers in Minnesota could affect the health of individuals incidentally exposed to bulb crusher exhaust. Although no current hazard exists, a public health hazard in the future could occur if these devices are used without adequate exhaust controls. Improvements in containment of mercury from fluorescent bulbs by drum-top crushers compared with current recycling methods have not been demonstrated. In addition, small, potentially mobile drum-top bulb crushers concentrate hazardous waste. This could contribute to the potential for mishandling these hazardous wastes and increase inadvertent and hazardous exposures to mercury. The use of drum-top bulb crushers can clearly expose people, including the general public, to hazardous mercury vapor concentrations. Design changes in the drum-top bulb crusher could likely reduce mercury emissions.

The MPCA notified the company that MPCA will not allow the use of drum-top bulb crushers in Minnesota.

Recommendations

MDH supports the current ban on the use of drumtop bulb crushers in Minnesota. If the MPCA allows the use of drumtop bulb crushers in the future, work practices and regulations should be established that are protective of human health and the environment. Among the recommendations for crusher regulation and improvements are:

1. Regulate the handling and disposal of drums.
2. Regulate the replacement of filters (including the particulate, HEPA and charcoal filters) and drum-top crusher maintenance.
3. Require testing of mercury emissions during operation.
4. Decrease the vacuum in the bulb crusher.

Public Health Action Plan

Currently, the MPCA has prohibited the use of bulb crushers in Minnesota. EPA should conduct a broad investigation of emissions from mercury-containing bulbs, and determine national regulations and policies that can reduce overall mercury emissions from bulbs and decrease potential exposures of individuals who may be incidentally or occupationally exposed to mercury from recycling operations.

This consultation was prepared by:

Carl Herbrandson, Ph. D.
Toxicologist
Site Assessment and Consultation Unit
Environmental Surveillance and Assessment Section
Minnesota Department of Health

References

[ATSDR] Agency for Toxic Substances and Disease Registry. 1999. Toxicological profile for mercury. Atlanta: US Department of Health and Human Services; 1999 Mar. Available at URL: http://www.atsdr.cdc.gov/toxprofiles/tp46.html.

Air Cycle Corporation. 2002. Bulb Eater™ Model 55 VRS specifications sheet. Maywood, Illinois: Air Cycle Corporation.

Aucott M, McLinden M, and Winka M. 2003. Release of mercury from broken fluorescent bulbs. J Air Waste Manag Assoc 53(2):143–51.

Barr Engineering Company. 2001. Substance flow analysis of mercury in products. Prepared for Minnesota Pollution Control Agency, St. Paul, Minnesota. August 15, 2001. Available at URL: http://www.pca.state.mn.us/publications/hg-substance.pdf.

[CA OEHHA] California Office of Environmental Health Hazard Assessment. 2001. Reference exposure levels. Sacramento: California Office of Environmental Health Hazard Assessment; 2001 Jan 22. http://www.ca oehha.org/air/hot_spots/index.html.

Energy Star. ENERGY STAR® Buildings Manual: Lighting. Washington DC: US Environmental Protection Agency. Available at URL: http://estar7.energystar.gov/ia/business/Lighting.pdf.

[EPA] US Environmental Protection Agency. 1997. Mercury study report to Congress, volume II: an inventory of anthropogenic mercury emissions in the United States. Washington DC: US Environmental Protection Agency; 1997 Dec. Available at URL: http://www.epa.gov/ttn/oarpg/t3/reports/volume2.pdf.

[EPA] US Environmental Protection Agency. 1998. Mercury emissions from the disposal of fluorescent lamps; final report. Washington DC: US Environmental Protection Agency; 1998 Mar 31. Available at URL: http://www.epa.gov/epaoswer/hazwaste/id/merc-emi/merc-pgs/emmrpt.pdf.

[EPA] US Environmental Protection Agency. 2001. Water quality criterion for the protection of human health: methylmercury. Washington DC: US Environmental Protection Agency; 2001 Jan. Report EPA-823-R-01-001. Available at URL: http://www.epa.gov/waterscience/criteria/methylmercury/merctitl.pdf.

[EPA] US Environmental Protection Agency. 2003. Integrated risk information system (IRIS). Cincinnati: US Environmental Protection Agency.

[MN OEA] Minnesota Office of Environmental Assistance. 2003. Email from John Gilkeson, MN OEA, to Carl Herbrandson, Minnesota Department of Health, regarding fluorescent light bulbs in use. October 7, 2003.

[MPCA] Minnesota Pollution Control Agency. 2002. Email from Joe Carruth, MPCA, to Scott Beierwaltes, Air Cycle Corporation, regardin drum-top crushers in Minnesota. March 13, 2002.

[MPCA] Minnesota Pollution Control Agency. 2003. Letter from Ned Brooks, MPCA, to Joanne Cassidy, EPA Region 3, regarding [68 FR 11981] Virginia: proposed and immediate final authorization of state hazardous waste management program revision. April 14, 2003.

Moore E, Swain E, Brist J, O'Keefe P. 1996. Recycling fluorescent and high-intensity discharge lamps. J Solid Waste Tech Manag 23(1):44–52.

[NEMA] National Electrical Manufacturers Association. 2000. Environmental impact analysis: spent mercury-containing lamps. 4th ed. Rosslyn, Virginia: National Electrical Manufacturers Association; 2000 Jan. Available at URL: http://www.nema.org/papers/enviimpact.doc.act.doc.

CERTIFICATION

This Drum-top bulb crusher demonstration at the Minneapolis-St. Paul International Airport Health Consultation was prepared by the Minnesota Department of Health under a cooperative agreement with the Agency for Toxic Substances and Disease Registry (ATSDR). It is in accordance with approved methodology and procedures existing at the time the health consultation was begun.

Signed copy available on request

Technical Project Officer, SPS, SSAB, DHAC, ATSDR

The Division of Health Assessment and Consultation, ATSDR, has reviewed this public health consultation and concurs with the findings.

Signed copy available on request

Chief, State Program Section, SSAB, DHAC, ATSDR

Attachment #1

Minnesota Department of Health - Carl Herbrandson, PhD 2/7/02
RfC Calculation for elemental mercury

Critical Effect
Hand tremor; increases in memory disturbances; slight subjective and objective evidence of autonomic dysfunction (Primary study - chloralkali, fluorescent, acetaldehyde workers)

EPA RfC Calculation

Experimental Dose:	**UF**	**MF**	**RfC**
NOAEL: None	30	1	$3x10^{-4}$ mg/m^3
LOAEL: 0.025 mg/m^3			
LOAEL (ADJ): 0.009 mg/m^3			

ATSDR MRL Calculation

			MRL
NOAEL: None	30	1	$2\ x10^{-4}$ mg/m^3
LOAEL: 0.025 mg/m^3			
LOAEL (ADJ): 0.006 mg/m^3			

California OEHHA Chronic REL Calculation

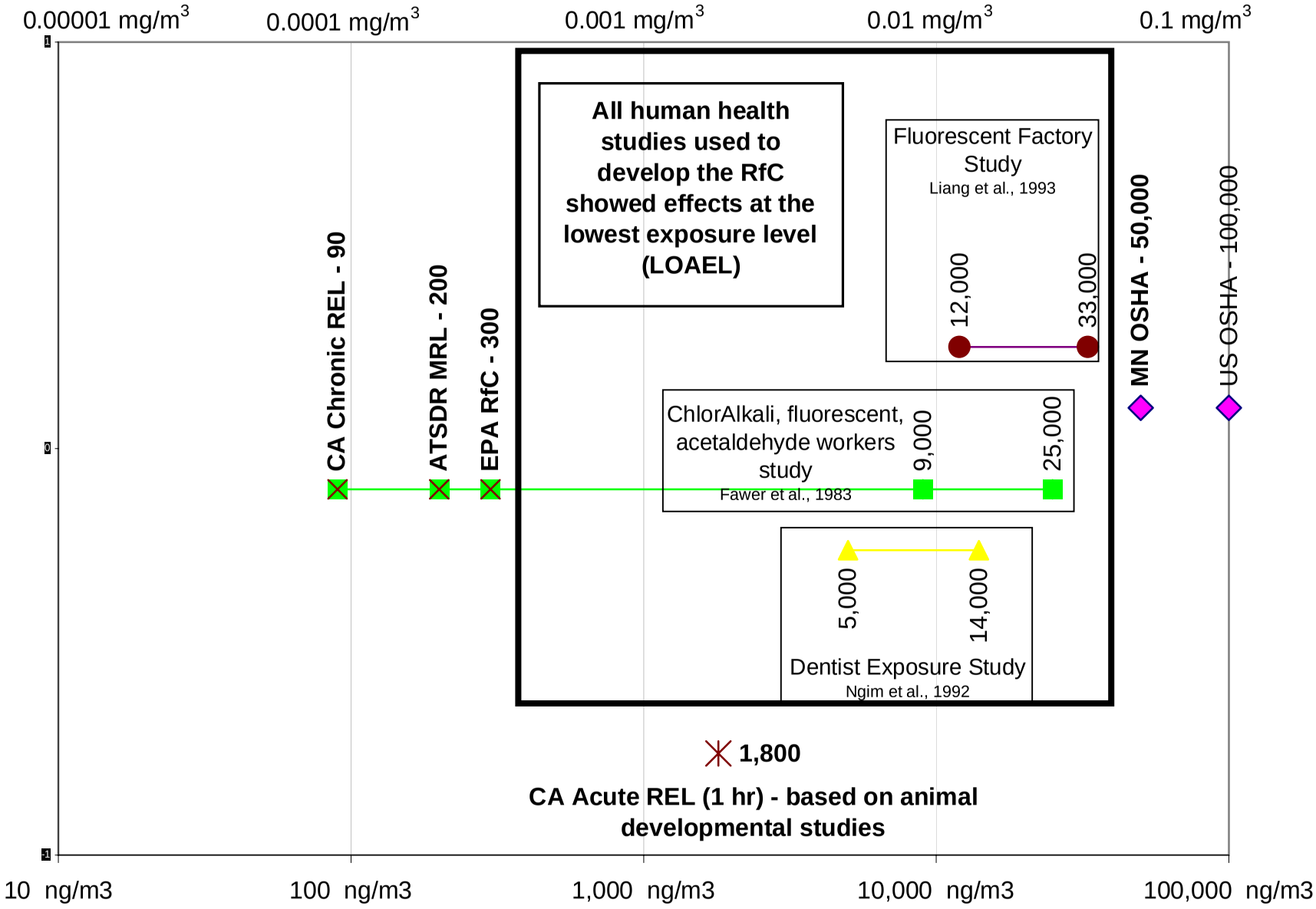
			Chronic REL
NOAEL: None	100	1	$9\ x10^{-5}$ mg/m^3
LOAEL: 0.025 mg/m^3			
LOAEL (ADJ): 0.009 mg/m^3			

California OEHHA Acute (1 hr) REL Calculation

Critical Effect: Significant dose-dependent deficits in behavior at 3-7 months, of rats exposed *in utero*

			Acute (1 hr) REL
	1000 ttl UF	1	$1.8\ x10^{-3}$ mg/m^3
NOAEL: None	10X – LOAEL UF		
LOAEL: 1.8 mg/m^3	10X – Interspecies UF		
(Rat study)	10X – Intraspecies UF		

Attachment #2



Attachment #3

From: Carruth, Joe
Sent: Wednesday, March 13, 2002 9:51 AM
To: 'Beierwaltes, Scott'
Cc: 'Dietrich, Marv J'
Subject: Drum-Top Crushers in Minnesota

Scott:

MPCA, County, OEA, and Health Department staff met on Wednesday this week to discuss the Bulb-Eater. The focus of the discussion was to sort out the findings from the Northwest pilot test, discuss the merits of allowing drum-top crushers in Minnesota, and define possible regulatory frameworks that might work for drum-top crushers. The discussion went many directions. The primary issues discussed were mercury containment of the crushed lamps, worker exposure from the crushing process, and the regulatory approaches.

It was agreed that crushers would provide convenience to large businesses using these machines with regards to storage space and shipping. It was also agreed that drum-top crushers might provide some long-term benefit to the mercury releases in Minnesota since they would allow a more convenient means of getting lamps to recyclers especially if they were used at locations where homeowners might access them.

We could not, however, easily conclude that these machines would provide a significant improvement to the existing recycling options from an environmental perspective (mercury containment). And, containment of mercury is one of the primary criteria that EPA needs to see in a state's application for the crushing of lamps in the authorization package for the universal waste rule. The following excerpt from the federal register provides an indication of EPA's terms for approval. The state was not convinced that drum-top crushing would be equivalent to the federal prohibition as required below.

"EPA will consider authorization of state programs that include provisions for controlling treatment and crushing of universal waste lamps, where the state program application includes a demonstration of equivalency to the federal prohibition. Factors the Agency would expect such an application to address include the effectiveness of technical requirements in controlling emissions of hazardous constituents, the level of interaction of regulated entities with the regulatory agency to ensure compliance with control requirements, and other factors demonstrating that the state regulatory program would be equivalent to the federal treatment prohibition."

There were other issues that we could not address satisfactorily with current data. Current worker exposure standards (OSHA) do not appear to be protective

of workers. New data suggests that the OSHA numbers are too high and the numbers from the pilot test did not clearly show that the exposure numbers were below numbers compiled from recent studies.

It was not clear and compelling that drum-top crushers would provide an improvement to the bottom-line mercury picture in Minnesota. It was clear, however, that more time and data was needed. In light of the current resource crunch at the MPCA, we do not have the necessary resources to collect the necessary additional data to answer all of our questions re: the use of these units.

It was, therefore, decided that the MPCA would not allow the use of drum-top crushers at this time nor could it commit to collecting and compiling the necessary data to complete the evaluation properly at this time. The MPCA, will continue to monitor the regulatory landscape and if EPA or another state can answer many of the questions outstanding, we would revisit the topic again.

Joseph P. Carruth, P.E.
Senior Engineer
Industrial Water and Land Sectors Unit
Majors Water and Land Section
Majors and Remediation Division
Minnesota Pollution Control Agency

telephone (651) 297-8372
fax (651) 297-8683
joe.carruth@pca.state.mn.us

Attachment #4

Ms. Joanne Cassidy Mailcode 3WC21
RCRA State Programs Branch
U.S. Environmental Protection Agency, Region 3
1650 Arch Street
Philadelphia, PA 19103

Re: Virginia: Proposed and Immediate Final Authorization of State Hazardous Waste Management Program Revision [68 FR 11981]

Dear Ms. Cassidy:

The Minnesota Pollution Control Agency (MPCA) respectfully submits this letter regarding the proposal and "immediate final approval" of Virginia's State Hazardous Waste Program published at 68 FR 11981-11986, 12015 (March 13, 2003). This *Federal Register* notice states that the proposal is believed to be "not controversial," that no opposing comments are expected, and that the proposal will be adopted immediately unless adverse comment is received.

These comments are limited to the portion of the "immediate final approval" relating to drum top crushers for hazardous waste lamps, addressed at 68 FR 11985. Minnesota opposes approval of the use of drum top lamp crushers because we believe that their use is not protective of human health and the environment, and because approval of their use would establish an undesirable precedent for management of mercury-containing lamps under federal and state laws and rules.

The issue of whether and under what circumstances to allow the use of drum top lamp crushers is one of national and international significance because of mercury's properties as an atmospherically transported persistent bioaccumulative toxic substance. Mercury reduction and management is being addressed by many states, including Virginia, through the Quicksilver Caucus and other organizations and coalitions. Mercury reduction and management is also addressed by a number of ongoing international discussions and agreements, including the recent United Nations Environment Program (UNEP) Governing Council decisions that international action on mercury is warranted, and to establish a Mercury Unit within UNEP.

There should be no decision to approve the use of drum top lamp crushers until all parties have had a chance to fully review and comment on the data that U.S. Environmental Protection Agency (EPA) and states are currently collecting on the effectiveness of this management practice. Interested parties need to have sufficient opportunity to review and discuss the full range of policy options regarding the use of drum top lamp crushers.

This letter was developed in consultation with the Minnesota Department of Health (MDH) and the Minnesota Office of Environmental Assistance (MOEA). These agencies conducted field testing of a drum top lamp crusher unit in February 2002. Based on the results of that testing, the MPCA declined to allow the use of drum top lamp crushers in Minnesota. Further discussion of test results and associated concerns can be found on pages 4-5 of this letter.

Minnesota opposes approval of the use of drum top lamp crushers for the following additional reasons:

1. Some states, including Minnesota, have determined that lamp crushing constitutes treatment and therefore anyone crushing their own lamps must obtain treatment technology approval or a full Subpart B TSDF permit under RCRA Subtitle C from the MPCA. Commercial lamp recyclers may operate under a Compliance Agreement with the MPCA or under a TSDF permit. To date, EPA has not addressed the question of whether lamp crushing constitutes treatment.

2. The standards that are contained in the *Federal Register* notice are inadequate to protect sensitive populations. The federal OSHA standard of 100,000 ng/m^3 was developed as an occupational standard for a healthy adult male worker, not sensitive populations such as infants and children, or even for working pregnant women. At a minimum, any standard used to evaluate drum top lamp crushers should take into account exposure to women of childbearing age, and potentially young children, if air circulates to facilities such as onsite day care centers. Moreover, this federal OSHA standard was set perhaps 30 years ago, long before it was recognized that chronic, low level exposure to mercury can be associated with developmental and neurological effects. Subtle adverse neurological effects have been shown to be associated with average occupational exposures of 14,000 to 33,000 ng/m^3 mercury vapor (Ngim et al. 1992, Fawer et al. 1983, Liang et al. 1993, and others). Many states, including Minnesota, have set their OSHA standards at levels lower than the federal OSHA standard because they have deemed the federal standard insufficiently protective. EPA has established a Reference Concentration (RfC) for mercury vapor at 300 ng/m^3, which is assumed to be protective of the general public for chronic exposure durations. In addition, California has established an acute Reference Exposure Limit (REL) at 1800 ng/m^3.

3. The standards that are contained in the *Federal Register* notice are inadequate for environmental protection. Crushers operating in compliance with federal OSHA standards will still release significant amounts of mercury to the environment.

4. If drum top crusher use was limited to known licensed facilities, states would have a chance to monitor operations. If drum top crushers are allowed to operate ubiquitously with little oversight, there is a significant chance of improper equipment operation and/or management of crushed lamp material. The technology and price of a crusher lends itself to poor quality imitation. Minnesota regulators have found crude lamp crushers that operate open to the atmosphere, with cloth bags of crushed lamps alongside. Crushed lamps lend themselves to mismanagement as their volume is $1/100^{th}$ that of the uncrushed lamps. They are easier to hide, dump, or “bury.”

5. Site contamination and worker exposure are serious concerns. One Minnesota solid waste transfer facility wanted to run a lamp crushing pilot project but declined over lack of assurance that it could do this without contaminating its employees and its facility with mercury.

6. Field measurements, including measurements made in Minnesota, demonstrate that this equipment cannot consistently meet the federal OSHA standard noted above, much less a lower state OSHA standard or a health based exposure limit or reference concentration. Releases and failures are episodic, unpredictable, and invisible. Continuous mercury vapor monitoring will be necessary to ensure compliance with any reasonable health-based or environmental standard.

7. It is our understanding that a government-sponsored drum top lamp crusher test had to be stopped because the air mercury vapor levels exceeded the federal OSHA standard by a factor of four.

8. Region 3's Approval Memo, "Equivalency Demonstration: Authorization of Virginia's Universal Waste mercury lamp crushing regulations," dated February 3, 2003, contains no empirical data or objective analysis to support the approval decision. It appears to assume that lamp crushing is beneficial, and then sets out to establish the case for it. It assumes a worst case scenario for releases from broken lamps destined for a central recycling facility, while it assumes a best case scenario for releases from drum top crushers. This best case scenario is based on optimistic manufacturer assumptions that are not supported by empirical data. There is no field evidence which can substantiate that this equipment can be consistently operated in compliance with the OSHA standard of 100,000 ng/m^3 and a filter efficiency of 99.97 percent for particles > 0.3 microns. Moreover, a particulate efficiency standard is largely irrelevant since the crusher creates mercury vapor that is not captured in a particulate filter.

Instead of pursuing this matter in an individual state authorization decision, we encourage EPA to undertake further policymaking on drum top lamp crushing in a procedural context that both facilitates national consistency and a full discussion of the relevant issues following an opportunity for review of the data obtained from ongoing equipment testing. EPA and other interested parties need the opportunity to carefully consider the following factual and policy issues:

- Under what circumstances is a worker safety standard for mercury also protective of the environment, particularly under the "equivalency" standard articulated by EPA in the universal waste rules? Worker safety standards are not equivalent to environmental standards.
- To what extent will allowing lamp crushing increase the emissions of mercury, based upon the most current testing data available? How would such an increase affect overall mercury reduction strategies at the state, national, and international levels?
- Whether and under what circumstances a healthy male adult worker standard is appropriate for a contaminant like mercury? Because mercury is a developmental toxin, at a minimum

the exposure standard should be protected of a fetus (i.e., closer to the EPA RfC of 300 ng/m^3).

- If crushers are allowed at generator locations, are there operating conditions such as segregated air flow that should be considered by states or regions when considering these requests? What are the environmental implications of this? In addition, should lamp crushing be allowed at any generator location (as a "low risk" activity) or should it be allowed only at facilities with certain operational capabilities and/or hazardous waste Large Quantity Generator (LQG) or TSDF status? Minnesota found significant mercury contamination at a closed centralized lamp crushing operation that used state of the art equipment. Operating within more liberal federal OSHA exposure limits, might crushing operations at generator sites leave even greater contamination? Should ubiquitous crushing operations be monitored, limited or prohibited?
- What type of regulatory program can be effectively and consistently implemented and enforced with the current resource constraints faced by most state and local governments?
- What are the appropriate legal and contractual responsibilities of the lamp crusher equipment vendors with regard to ensuring proper use and maintenance of the equipment, ensuring proper worker exposure monitoring, and ensuring proper management of crushed lamps and other wastes (e.g., carbon filters) generated through the use of this equipment? How would equipment vendors and crusher operators regulate themselves? How would EPA and the states regulate the quick-buck lamp crushers likely to flood the market but unlikely to contain the mercury?
- Because mercury is a pollutant that knows no geographic boundaries, states and regions should not be making their own regulations to address drum top lamp crushers without input from other states, regions and EPA headquarters. Policies and regulations should be discussed and established through a national dialogue that takes these and other issues into account.

Minnesota measurements of lamp crusher mercury vapor levels.

The MPCA, in cooperation with MDH, MOEA, local RCRA regulators, a manufacturer of drum top lamp crushers, and a LQG, tested mercury vapor levels in air during use of a crusher at the LQG's site. Levels were tested with a Lumex mercury vapor analyzer.

The test was initiated with a clean drum and carbon filter. Mercury vapor levels at or near the carbon filter exhaust exceeded the Lumex instrument's maximum quantifiable reading of 50,000 ng/m^3 each time a lamp was fed into the machine and these levels dropped very slowly. This exhaust was about two feet from the breathing zone of the employee. Mercury vapor levels in the breathing zone of the employee were consistently measured at 20,000 to 50,000 ng/m^3, while lamps were being fed into the crusher, occasionally exceeding the instrument's limit. Shards of lamp glass and puffs of lamp phosphor were regularly seen being ejected from the lamp feed tube as lamps were fed in. When the crusher was operated for several minutes without any lamps being fed in, the levels at the filter exhaust dropped to about 8,000 ng/m^3 and stabilized at that level.

Minnesota is also concerned about other issues, including but not limited to:

- Resources to enforce standards for lamp crushing equipment and operation, e.g.,
  - How to limit the numbers of crushing operations;
  - How to know where lamp crushing is occurring and monitor worker safety and environmental protection;
  - How to monitor whether crushed lamps are getting recycled;
- The need for continuous mercury vapor level monitoring at each crusher due to the unpredictability and invisibility of equipment failure and mercury release;
- Potential high instantaneous mercury exposure to workers and release to the environment when the crushing unit is removed from a drum full of crushed lamps;
- Potential mercury release from the unit when it is not in use;
- Proper maintenance of the equipment and filters, including scheduled filter replacement and monitoring for filter breakthrough or failure;
- Proper maintenance and routine component replacement since owners of crushers may be more interested in saving money than maintaining equipment as prescribed;
- Improper management of crushed lamps, since crusher equipment vendors sell equipment, not lamp recycling services;
- Hazardous waste and OSHA enforcement at many dispersed sites using drum top crushers, and;
- The consequent need to issue permits or licenses, or otherwise track each crusher's compliance and recordkeeping.

Based on test measurements and the concerns noted above, Minnesota has determined that the use of drum top lamp crushers is not protective of human health and the environment and is not allowing their use.

If you have any questions please contact me at (651) 296-7242 or ned.brooks@pca.state.mn.us or John Gilkeson, MOEA at (651) 215-0199 or john.gilkeson@moea.state.mn.us.

Sincerely,

Ned T. Brooks
Mercury Reduction Coordinator
Policy and Planning Section
Majors and Remediation Division

NTB:jae

cc: Patricia A. Bloomgren, Director, Environmental Health Division, MN Department of Health
David Cera, Supervisor, Business Assistance Unit, MN Office of Environmental Assistance
Alden Hoffman, Industrial Hygiene Manager; OSHA Division, MN Department of Labor and Industry

References:

Ngim, C.H., S.C. Foo, K.W. Boey and J. Jeyaratnam. 1992. Chronic neurobehavioral effects of elemental mercury in dentists. Br. J. Ind. Med. 49: 782-790.

Fawer, R.F., U. DeRibaupierre, M.P. Guillemin, M. Berode and M. Lobe. 1983. Measurement of hand tremor induced by industrial exposure to metallic mercury. J. Ind. Med. 40: 204-208.

Liang, Y-X., R-K. Sun, Y. Sun, Z-Q. Chen and L-H. Li. 1993. Psychological effects of low exposure to mercury vapor: Application of a computer-administered neurobehavioral evaluation system. Environ. Res. 60: 320-327.