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EVALUATION OF MERCURY EMISSIONS FROM FLUORESCENT LAMP CRUSHING

CONTROL TECHNOLOGY CENTER

Sponsored by

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PREFACE

This project was funded by EPA's Control Technology Center (CTC) and prepared by EC/R Incorporated. The CTC was established by EPA's Office of Research and Development (ORD) and Office of Air Quality Planning and Standards (OAQPS) to provide technical assistance to State and local air pollution control agencies. Several levels of assistance are provided by the CTC. First, a CTC HOTLINE is available to provide telephone assistance on matters relating to air pollution control technologies. Second, more in-depth engineering assistance is provided when appropriate. Third, the CTC can provide technical guidance by designing technical guidance documents, developing personal computer software, and presenting workshops on technology matters. The CTC also serves as the focal point for the Federal Small Business Assistance Program, maintains the Reasonably Available Control Technology/Best Available Control Technology/Lowest Achievable Emission Rate (RACT/BACT/LAER) Clearinghouse, and provides access to the Global Greenhouse Gases Technology Transfer Center. Information concerning all CTC products and services can be accessed through the CTC Bulletin Board System (BBS) which is part of the OAQPS Technology Transfer Network (TTN).

This report is the result of a request for technical assistance from the Florida Department of Environmental Protection. Florida was concerned about potential mercury emissions and control options for a proposed facility that would crush fluorescent lamps for recycling. This report presents an evaluation of mercury emissions from the crushing of fluorescent light bulbs. Background information on mercury-containing fluorescent lamps and their disposal is also presented. These light bulbs are crushed as the first step in recovery of mercury, or disposal of the bulbs in a landfill or incinerator. Three different crushing systems are described in detail, and variations on these systems are also discussed. The report describes the air pollution controls on each system, and emissions of mercury from the crushing process are estimated. This information provides the basis for evaluating the potential for mercury emissions from the crushing of fluorescent light bulbs, and the efficacy of available air pollution controls in limiting these emissions.

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1.0 INTRODUCTION

1.1 PROJECT GOAL

This project is sponsored by the Control Technology Center (CTC) of the U.S. Environmental Protection Agency (EPA), Research Triangle Park, North Carolina. The purpose of this project is to evaluate the processing of spent fluorescent lamps, and technology for the control of mercury emissions from this process. The procedure involves crushing fluorescent light lamps, which results in mercury emissions, either in liquid or vapor form. The lamps are crushed as the first step in reprocessing. Subsequent to crushing, the broken lamps are either landfilled, incinerated, or recovered. This study addresses emissions from the crushing of fluorescent lamps and the initial handling of the resulting crushed material. The study does not cover subsequent mercury recovery and refining operations.

1.2 OVERVIEW OF DOCUMENT

This document provides brief background information on the use and disposal of fluorescent lamp tubes. The major emphasis of the document is on the lamp crushing process and associated mercury emission control devices. Three different crushing processes are discussed, as well as the air pollution controls in practice, and the resulting air emissions. This provides the basis for an evaluation of the effectiveness of various crushing methods and the efficacy of different air pollution controls. Some relevant variations on these crushing processes are also described, along with their potential for emissions. This document does not address the retorting of mercury-containing material for the recovery and recycling of elemental mercury, or the disposal of mercury-containing wastes, resulting from crushing operations, in landfills. However, these operations are mentioned incidentally throughout the document, as they are closely associated with crushing operations.

2.0 BACKGROUND INFORMATION ON FLUORESCENT LAMPS

2.1 LAMP USAGE

Fluorescent lamps are widely used in businesses, as they provide an energy-efficient source of lighting. The commercial and industrial sectors dominate usage of fluorescent lamps, accounting for over 90 percent of total usage.[1] Approximately five hundred million lamps were manufactured in 1991.[1] It is possible that this number will increase substantially, as the EPA promotes the use of fluorescent lighting as part of its Green Lights program, which is designed to reduce energy consumption. Each lamp has a lifetime of three to four years under normal use. Fluorescent lights are designed so that approximately half of them will operate after 20,000 hours of operation.[1] Where these lamps are being used on a small scale, they are generally replaced as they burn out, one at a time. However, in large companies and industries, this method is not practicable, and, therefore, group relamping is done on a regular basis. Typically, group relamping is performed at 15,000 hours, or 75 percent of the lamp's rated life.[1] This translates to replacement every two years for continuous operations, and every three to five years for noncontinuous operations, which are much more common. Approximately 20 percent of all lamps are currently replaced annually.[1] Group relamping operations generate large quantities of lamps to be disposed of at a single time.

2.2 DESCRIPTION OF FLUORESCENT LAMPS

A typical fluorescent lamp is composed of a sealed glass tube filled with argon gas at a low pressure (2.5 Torr), as well as a low partial pressure of mercury vapor, thus the tube is a partial vacuum.[1,2] The inside of the tube is coated with a powder composed of various phosphor compounds. The composition of this powder is shown in Table 1.[1] Tungsten coils, coated with an electron emitting substance, form electrodes at either end of the tube. When a voltage is applied, electrons pass from one electrode to the other. These electrons pass through the tube, striking argon atoms, which in turn emit more electrons. The electrons strike mercury vapor atoms and energize the mercury

Table 1: Elemental Analysis of Used Fluorescent Lamp Powder[1]

Element	**Concentration (mg element/kg phosphor powder)**
Aluminum	3,000
Antimony	2,300
Barium	610
Cadmium	1,000
Calcium	170,000
Chromium	9
Cobalt	2
Copper	70
Iron	1,900
Lead	75
Magnesium	1,000
Manganese	4,400
Mercury	4,700
Nickel	130
Potassium	140
Sodium	1,700
Zinc	48

vapor, causing it to emit ultraviolet radiation. As this ultraviolet light strikes the phosphor coating on the tube, it causes the phosphor to fluoresce, thereby producing visible light. Thus, the mercury in these lamps is critical to the production of light. The life of the lamp is determined by the life of the electron producing coating on the cathode, which diminishes as the lamp is operated.[2] The most commonly used fluorescent lamp is the 40 watt, 4 foot long tube, although smaller, larger and differently shaped lamps are also used.[1]

The amount of mercury in fluorescent lamps varies considerably with manufacturer, and even possibly within manufacturers.[2] Tables 2 and 3 show the mercury content of used and new fluorescent lamps made by various manufacturers. These results are from a study conducted by Science Applications International Corporation for the EPA.[2] The National Electric Manufacturers Association (NEMA) estimates that in 1990, the average fluorescent lamp contained 41 mg of mercury per lamp. NEMA predicts that this will decrease to 27 mg by 1995.[1]

2.3 DISPOSAL OF LAMPS

In a study report prepared for EPA Office of Solid Waste by Research Triangle Institute (RTI) entitled "Management of Used Fluorescent Lamps: Preliminary Risk Assessment," it is estimated that approximately 600 million lamps are disposed each year.[1] Currently, the largest fraction of lamps are disposed in the waste stream; 82 percent of lamps are landfilled, 16 percent are incinerated, and only 2 percent are recycled.[1] RTI estimates, based upon Department of Commerce data and industry information, that the total amount of mercury entering the U.S. municipal solid waste system annually (1989) is 643 Mg.[1] The contribution from fluorescent lamps is approximately 24.4 Mg, or 3.8 percent.[1]

The amount of mercury emitted from a spent lamp depends on

Table 2: Mercury Content of Used Fluorescent Lamps[2]

Manufacturer	Mercury Concentration (mg of mercury/lamp)
Westinghouse	21.0
Westinghouse	16.6
Westinghouse	17.2
Westinghouse	61.5
General Electric	24.4
General Electric	23.1
General Electric	0.72
General Electric	36.1
General Electric	115.0
General Electric	27.2
Dayton	22.5
Phillips	17.5
General Telephone & Electric	48.0
Minimum	0.72
Maximum	115.0
Average	33.14
Standard Deviation	28.91

the way the lamp is handled after it is changed. Discarded lamps may be transported in two ways: in garbage trucks as household or commercial trash, or in closed vans or trailers as part of a bulk relamping program. In the former case, used lamps are simply disposed in a dumpster, which is then transported to the landfill by a garbage truck. It is assumed that all of the lamps in garbage trucks are broken and that vaporized mercury in these trucks finds its way to the atmosphere.[1] In the case of bulk relamping programs, the discarded lamps are packed in corrugated containers from which the new lamps were taken and are then

Table 3: Mercury Content of New Fluorescent Lamps[2]

Manufacturer	Mercury Content (mg of mercury/lamp)
General Electric	35.8
General Electric	40.2
General Electric	29.3
General Electric	33.0
General Electric	18.8
General Electric	15.1
General Electric	14.3
General Electric	15.7
General Electric	19.1
General Electric	20.5
General Electric	44.8
General Electric	15.7
Minimum	14.3
Maximum	44.8
Average	25.19
Standard Deviation	10.87

loaded into enclosed vans or trailers for removal to a landfill. In this case, it is assumed that few lamps are broken and practically all of the mercury is retained in the landfill.[1]

In any case, recovery of the mercury in lamps appears to be desirable, in that the net amount of mercury ultimately released to the environment is reduced. The recovery process begins with the crushing of lamps to extract the white phosphor powder, which contains the bulk of the mercury. This powder is then put into a mercury retort to recover elemental mercury.

There are presently few mercury recycling facilities in the country. Most facilities are located in California or Minnesota. The State of Minnesota is now enforcing a requirement passed by the Minnesota Pollution Control Agency (MPCA) on May 8, 1992 that declares used fluorescent and high intensity discharge lamps with specified levels of mercury are hazardous waste, and as such must not be landfilled if a recycling option is available.[3] The State of Minnesota is also requiring that businesses store their spent lamps until such a facility is available to them.[3] This has provided a substantial impetus to development of recycling and recovery operations in Minnesota.[3]

2.4 MERCURY EMISSIONS

The disposal of mercury-containing fluorescent lamps and the potential for emissions therefrom is of concern because mercury is a highly toxic heavy metal, which bioaccumulates through the food chain.[1] Mercury also has a vapor pressure of $2X10^{-3}$ mm ($25^{o}C$) and is volatile at room temperature. Emissions of mercury in liquid or vapor form, therefore, need to be considered. The volatilization pathway is especially significant with respect to human health concerns, as it results in ambient concentrations of mercury that can be absorbed through various pathways.[1] These include direct inhalation, or ingestion through the consumption of contaminated food products, particularly fish. Estimates on global and national mercury emission vary widely.

EPA's estimates of U.S. anthropogenic mercury emissions are somewhat incomplete, but indicate levels around 309 Mg/yr.[4] Coal-fired power plants, municipal solid waste combustors and industrial sources account for 110 Mg, 58 Mg, and 32 Mg per year, respectively (note that this is a worst-case estimate for coal-fired power plants; i.e., all mercury in the coal is emitted).[4] Based upon air emission and mass balance information received from the MRT AB mercury recovery system, RTI estimates that only

0.005 Mg of mercury are emitted each year from all recycling plants combined.[1] This number may have increased somewhat, because there are more recycling plants operating now than there were at the time of the study.

3.0 LAMP CRUSHING PROCESSES

The crushing of fluorescent lamps to separate the glass from the phosphor powder in the lamp is commonly the first step in recycling of mercury; although some companies use other methods, such as removal of the phosphor powder by air vortex or by flushing with hydrochloric acid.[1] Although separation of the phosphor powder and, hence, the mercury, from the glass and metal endcaps is necessary for recycling and recovery of mercury, it is not done only to facilitate this process. Crushing of mercury-containing fluorescent lamps is also done in order to reduce the volume of the lamps being disposed in landfills.

In this section, several different systems used for the crushing of fluorescent lamps are described. Information was gathered from RTI's "Management of Used Fluorescent Lamps: A Preliminary Risk Assessment,"[1] and through conversations with different individuals involved in the processing of fluorescent lamps. These individuals were from both recycling companies[5,6,7,8] and State agencies.[3,9]

Three different crushing systems are described in detail in the following sections. These are: (i) the basic crushing system; (ii) the MRS crushing system; and (iii) the Mercury Technologies crushing system. The basic system used to crush the fluorescent lamps is quite similar in many cases, and is a relatively simple process. Most of the differences between crushing systems reside in the air pollution controls they have in place to control mercury emissions from the crushing process. Thus, in the discussion of each system, particular attention will be paid to the controls in place, and, where data are available, the efficacy of those controls in reducing or eliminating mercury emissions into the environment.

3.1 BASIC CRUSHING SYSTEM

3.1.1 Crusher Design

The simplest of crushers is essentially a single unit, with a crusher mounted on top of a barrel, usually a 55-gallon drum. This system is used in many industrial facilities to crush their fluorescent lamps as a means to reduce the solid waste volume before disposing the material in a landfill.[10] In this version, light lamps are hand-fed to a feeder chute of variable length and diameter. This chute is not necessarily longer than the lamps being fed into it. The lamps pass to the crushing unit, typically consisting of motor-driven blades, which implode and crush the lamps. From here, the crushed powder drops into the barrel below the crusher.

3.1.2 Air Pollution Controls

In the simplest of these systems, there are no air pollution controls on the device.[10] The crushed lamps are collected in drums until they are full, and then the full drums are transported to one of several facilities. The crushed material may then be separated into glass, metal, and powder components. Typically, the untreated powder is then deposited in a landfill. This is currently the most common method of disposing these lamps.[1] Alternatively, the barrels may be transported to a mercury recovery facility, which will separate the mercury-containing phosphor powder from the crushed glass and aluminum endcaps, and recycle all the materials.

A more sophisticated version of this barrel-mounted crusher utilizes a negative air exhaust system to draw the crushed debris and prevent it from reemerging through the feeder tube.[11] The drawn air is then passed through a High Efficiency Particulate Air (HEPA) filter to remove particulate matter from the exhausted air flow. The crushed material is then disposed in one of the manners discussed above.

3.1.3 Emission Points and Estimates

In the simplified crushing systems discussed above, there are several emission points.[10] The feeder tube itself is a potential emission point. The length of this tube, as well as the length of the lamps being crushed, affects the magnitude of emissions from the feeder tube. Additionally, the juncture between the crushing unit and the receiving barrel below is a possible emission point, depending on how well the connection is sealed. Finally, an emission point of concern is the collection barrel itself. Whenever this barrel is removed from the crushing unit for disposal at another facility, the open area of the barrel constitutes a potential emission point. All these points are relevant when there are no air pollution controls in place. In the modified case, where negative air is employed, emissions through the feeder tube may be reduced or eliminated entirely, depending upon the strength of the air flow.

In many cases, actual emission estimates have not been determined; rather, occupational exposure estimates have been derived from ambient air measurements taken in the workplace.[10] For the case of the simplified system discussed above, Kirschner, et. al., conducted a workplace study of mercury emissions from a similar fluorescent lamp compaction unit. In this case, the compaction was performed to reduce volume prior to landfilling. This unit consisted of a crusher mounted on top of a 30 gallon drum, with a feeder tube of an unspecified length. When the study was undertaken, no air pollution controls were in place on this device. The scientists observed significant dust emissions from the mouth of the feeder tube, and the juncture between the crusher and the collection drum. Indoor ambient air monitoring revealed ambient mercury levels that varied widely with different lamp inputs (possibly due to manufacturer variability). Nonetheless, the measurements indicated levels of mercury near to, as well as above the Occupational Safety and Health Administration (OSHA) limits of 0.05 mg/m^3.[10,12] Results of this study are shown in Table 4. During the test, 300 lamps were crushed in a 20 minute period, yielding an average operational crushing rate of 15 lamps per minute.[10] The researchers concluded

Table 4: Airborne Mercury Levels Associated with Fluorescent Lamp Compaction Unit (mg/m^3)[10]

	Area Samples			Personnel Samples		
Sample	**A**	**B**	**C**	**D**	**E**	**OSHA Limit**
Distance (ft.)	**5**	**20**	**50**	**15**	**20**	
Background	0.0002	0.0010	0.0006	---	---	0.05
Trial 1	0.31	----	----	0.54	0.65	0.05
Trial 1, Time Weighted Average	----	----	----	0.02	0.03	0.05
Trial 2	3.00	0.09	0.10	2.23	1.82	0.05
Trial 2, Time Weighted Average	----	----	----	0.12	0.10	0.05

that such uncontrolled fluorescent lamp crushers should be considered emitters of mercury.[10]

Several controls were put in place in the crusher to determine if mercury emissions could be reduced: 1) gasketing was applied to seal the area around the connection between crusher and drum; 2) the crushing unit was housed entirely within a shed which allows fluorescent lamps to be fed in from outside; and 3) a 55 gallon disposable barrel was substituted for the collection barrel. In the third control, the disposable barrel became the final waste receptacle. When filled it was disposed directly to the company's sanitary landfill, rather than being emptied into a dumpster, thus eliminating one step in the transfer process, and reducing employee exposure to mercury emissions.

Preliminary tests indicated that all these measures were useful in reducing emissions.[10] Nonetheless, the authors concluded that fluorescent lamp crushing units should be considered emitters of mercury unless ventilation and adsorbent capabilities, such as carbon filters, are added.[10]

A further example of the problems with uncontrolled crushing devices is illustrated in the case of Quicksilver Products.[1] This company, located in California, briefly entered the business of fluorescent lamp crushing. Their lamps were crushed outside in a unit mounted on top of a 55 gallon drum. An air separation system was used to remove the phosphor powder and mercury from the glass. This facility was closed down for violations of safe operating practices. Extensive contamination was found around the facility; high concentrations of mercury were measured in the soil, rinse water, and on a nearby roof.

3.2 MRS CRUSHING SYSTEM

3.2.1 Crusher Design

Mercury Recovery Services (MRS) is a mercury recycling plant located in California. The information about their crushing process presented below was provided by the company.[7] The fluorescent lamp crushing apparatus operated by MRS is more sophisticated than the basic system described above, particularly in terms of the air pollution controls. The process currently in operation is described in detail here. However, the company is in the process of developing a new design which will be patented, thus, specific information on the new design is proprietary and is not included in this report. MRS did indicate that the new system will include a self-loading apparatus where lamps will be deposited for delivery to the crusher, and a totally enclosed operation to separate the glass, endcaps, and phosphor powder within the system.

The current crusher operated by MRS is a hand fed apparatus with two feeder chutes. One chute is 5 feet long, to accommodate 4 foot lamps, and the other tube is 9 feet, in order to accommodate 6 to 8 foot lamps. Each chute is placed at an angle, and has a 9 inch by 12 inch opening, which can accommodate several lamps at a time. The lamps are delivered down this angled tube onto a motor driven blade made of heavy gauge hardened steel rotating at 2700 rotations per minute. The rotating blades implode and crush the lamps as they arrive. The crushing unit has an operating capacity of 62.5 lamps per minute.

A vacuum system collects air from beneath the crusher, preventing mercury laden air from exiting through the feed tube. Material collected in the vacuum system first passes through a cyclone separator. This removes glass particles, which drop into the drum. Air from the cyclone separator contains phosphor powder and some mercury vapor. These are removed by further controls, as discussed below.

At the end of the process, the glass and aluminum are sent to recyclers. The phosphor powder is sent to a mercury recovery company for retorting and recovery of the mercury.

3.2.2 Air Pollution Controls

After passing through the cyclone, the air is pulled through to a baghouse, where 9 fabric filters trap particulate matter in the air stream. Every 45 seconds, these fabric filters are cleaned with a reverse pulse of air. The air leaving the baghouse is typically composed only of air and mercury vapor. This air and mercury vapor mixture continues through several more particulate matter filters and HEPA filters, to ensure that all particulates have been removed. From here, the exhaust is delivered to two 250-pound activated carbon beds, which trap the mercury vapor. These carbon beds are replaced at saturation, typically after two years. The airflow is then directed through yet more particulate matter filters to trap any carbon that may have been carried along from the activated carbon beds.

At this point in the air pollution filter chain, a five to ten horsepower pump exhausts the air flow into a mediator (essentially an area where air from the different sources is mixed prior to discharge into the warehouse area). Air is also being pumped from the containment room through the mediator on a continuous basis, and subsequently to another series of particulate filters and more activated carbon. Therefore, air from the crushing unit and the containment room is mixed, after filtration, and discharged into the warehouse area. Thus, in addition to cleaning the exhaust air from the crushing unit, the system cleans the air in the containment room six times per hour. Air flow through the filter chain is 25 cubic meters per minute (900 cubic feet per minute), on average. The entire crushing system and filter chain is enclosed within a containment room, which is itself within a warehouse. After all air has passed through the entire filter system and been cleaned, it is pumped into the containment room and to the warehouse, essentially a closed loop system. The only exchange of air with outside ambient air would occur incidentally in the warehouse, such as when doors are open and closed, or at points in the warehouse that are not airtight.

The entire process is vacuum sealed and monitored continuously for leaks and to ensure that air in the containment area is in compliance with OSHA regulations. In the case of a leak, work ceases until the leak is repaired, and then resumes. Effectively, the only time where levels of mercury in the workplace may approach the OSHA limit of 0.05 mg/m^3, is when lamps have been dropped and broken.[7] No efficiencies of control devices are cited; rather, MRS monitors constantly and bases their determination of adequacy on measured mercury levels in the workplace.

3.2.3 Emission Points and Estimates

This crusher is designed to ensure that there is no leakage of air from the system.[7] The opening through which the lamps are fed is a potential emission point, but strong negative air flow pulling on the crushing apparatus prevents emissions from resulting. Additionally, the negative air flow ensures that the entire filter process is vacuum sealed. The entire system is continuously monitored for leaks.

No emission estimates are available for this particular process, because the company monitors constantly for compliance with OSHA as its standard and bases their determination of control device adequacy on measured ambient mercury levels in the workplace. As noted above, the MRS crusher is controlled by a combination of fabric filtration and carbon adsorption.

To provide a basis for estimation of control device effectiveness in the fluorescent lamp crushing process, EC/R investigated other industries where carbon adsorbers are used to control mercury emissions. In the chlor-alkali industry, carbon adsorbers applied to mercury vapor streams attain outlet concentrations under 50 parts per billion (ppb), and sometimes as low as 1 ppb.[13] Although outlet concentrations have not been measured for a lamp crushing operation, it is reasonable to assume that comparable concentrations could be attained if the carbon adsorption system is well designed and operated. Therefore, using outlet concentrations from the chlor-alkali plants and the reported airflow for the MRS unit, mercury emissions would range from 0.2 to 10 mg per minute. [According to Bob Roberts, president of MRS, monitoring indicates ambient mercury levels well below the OSHA limit of 0.05 mg/m^3.]

3.3 MERCURY TECHNOLOGIES CRUSHING SYSTEM

3.3.1 Crusher Design

Mercury Technologies of Minnesota is one of only three companies in the United States using this particular technology.[6] The original developer of this technology was Mercury Technologies Corporation, a company that operates a mercury recycling and recovery facility in Hayward, California. The system is a completely enclosed design that feeds fluorescent lamps in one end to a crusher, passes the exhaust through an extensive filtering system, and delivers the powder to a thermal reduction unit (TRU), which recovers the mercury from the phosphor powder.[6] Thus, this system carries out the entire mercury recycling process, from the crushing of fluorescent light lamps to the retorting and reclamation of mercury from phosphor powder.

Lamps are hand-fed into feeder tubes of different lengths, depending upon the size of the lamps being processed. If 4-foot lamps are being processed, they are fed into a tube that is 5 feet long, and if 8-foot lamps are being processed, they are fed into a 9 foot feeder tube. The lamps are fed to the crusher, which implodes and crushes the lamps into small fragments. The operating capacity of the unit is 60 lamps crushed per minute.

As with the MRS operation, the entire process is conducted under negative airflow. The crushed debris is exhausted first to a cyclone, where the larger particles, such as crushed glass and aluminum endcaps are separated out. At this point, much of the phosphor powder drops out into a cyclone hopper. From this collection hopper, the phosphor powder, containing mercury, is transferred to the TRU via an enclosed auger conveyer, as described in the following section.

3.3.2 Air Pollution Controls

After the cyclone, the airflow proceeds to a baghouse, where fabric filters continue to remove particulate matter from the airstream. The fabric filters are cleaned with a reverse pulse mechanism, and the powder that drops out here is also routed to the cyclone hopper. The air stream leaving the baghouse proceeds to a HEPA filter, and then to a potassium iodide-impregnated carbon filter. This removes the mercury vapor, by precipitating it in the form of mercuric iodide (no removal efficiencies were cited). The air in the building that houses the self-contained unit is also under continual negative air pressure. Thus, all this air is drawn through the entire filter system as well. There is no exhaust to the outdoors. Rather, all air is recirculated back into the workplace. Air flow through the system is approximately 18 cubic meters per minute (650 cubic feet per minute).

From the cyclone hopper, the powder, which consists mainly of 6 to 12 μm particles, is auger-conveyed to the TRU. An auger conveyor is a tube with a 6-inch diameter, and a screw or helix-like component that pushes the powder up through the tube to the TRU. Here, the powder is retorted to recover separate fractions of elemental mercury and phosphor powder.

3.3.3 Emission Points and Estimates

Because of the design of this mercury recycling and recovery system, there is virtually no leakage of air from the lamp charge chute. As with the MRS system described above, the entire process is carried out under negative air pressure, which prevents emissions from the mouth of the feeder tube. Furthermore, because recovery of the mercury is carried out in the same self-contained unit as lamp-crushing, there is no point where the transfer of phosphor powder to a subsequent processing device can result in emissions.

Mercury Technologies of Minnesota monitors their indoor air regularly, and the company consistently operates with indoor levels of mercury of approximately 0.005 mg/m^3, which is an order of magnitude lower than the OSHA limit.[6] The plant is shut down if levels reach 0.01 mg/m^3.

No information is available regarding the particular effectiveness of different control devices; instead, the facility relies upon its workplace monitoring to ensure that emissions are restricted or eliminated. As previously stated, carbon adsorbers applied to mercury vapor streams in other industries typically achieve outlet mercury concentrations under 50 ppb, and sometimes as low as 1 ppb.[13] If it is assumed that these levels are attained by the Mercury Technologies system, then using these outlet concentrations and the reported air exhaust rate for the crusher, mercury emissions would range from 0.14 to 7 mg per minute.

3.4 OTHER VARIATIONS

The crushing systems discussed above demonstrate the range of available technology, and are generally representative of the fluorescent lamp reduction and recycling industry. After the most simple crushing units have been expanded upon, most of the differences between crusher systems result from differences in pollution control devices. Several industry representatives contacted during this study articulated the feeling that the basic crushers mounted on top of barrels are inadequate methods and pollute excessively.[6,7,8] This is due to the fact that, although most of the mercury is contained in the phosphor powder, a considerable percentage of the mercury is in vapor form, and therefore will not be removed by particulate capture methods. This leads to an environmental problem in the form of mercury emissions.

3.4.1 Transfer Operations

Removal of the collection barrel (55-gallon drums) from the collection device (e.g., cyclone separator, baghouse) and placing the seal and lid on it constitutes a potential emission point. The 55-gallon drums are Department of Transportation-approved vessels, and are sealed as soon as they are removed from the crushing device. USALights of Minnesota said that this procedure is carried out very rapidly to minimize emissions.[8] The workers involved in this operation all wear respirators and protective clothing during the operation to minimize their exposure to mercury. USALights replaces its barrels about once every two weeks.

Typically, when facilities do not recover mercury on-site, they must ship it elsewhere for further processing. In Minnesota, this is done under a hazardous waste manifest, and all mercury is shipped with a licensed hazardous waste transporter.[8]

3.4.2 Removal of Endcaps

An operation which is not discussed in detail here, because it does not involve crushing of the light lamps, is carried out by a company called Lighting Resources.[1] Lighting Resources received a variance for treatment of used fluorescent lamps in California in January 1991. The variance allows operation of equipment as a prototype unit to determine optimal treatment conditions.

Instead of crushing the lamps, this company's process cuts off the endcaps, thereby releasing the vacuum in the lamp, and then removes the phosphor powder with an air vortex. The phosphor powder is then collected in a cyclone separator. The process is operated at a low temperature (actual temperature value was not reported) in the process room to reduce volatilization of mercury.[1]

3.4.3 MRT AB Mercury Recovery Systems

MRT AB, a company based in Sweden with worldwide operations, has one of the more refined mercury reclamation operations in the world.[1] The operation is a full scale system for the recovery of mercury from fluorescent lamps, batteries and other mercury-containing waste. They use a batch distillation retort to reclaim the mercury, and have developed a modular design that allows their plants to handle widely varying numbers of inputs (lamps). The smallest of their units is a single lamp crusher with a distilling unit that can handle up to 200,000 lamps per year.

The entire system is enclosed and operated under negative pressure to minimize fugitive emissions. The system vents to carbon filtration units for mercury emission control. MRT AB closely monitors emissions from all their systems. Based on measurements downstream of all their charcoal filters, MRT states that air emissions from their crush/sieve unit has an average mercury concentration of 0.5 $\mu g/m^3$, resulting in annual emissions of 1 g/year.[1] Emissions from the crush/sieve ventilation room are also 0.5 $\mu g/m^3$, yielding 5.25 g/year in annual emissions.[1] The differences are due to differences in operating hours. No inlet concentrations or control device efficiencies were reported. The MRT system is used successfully by RecycLights of Minnesota.[5]

4.0 MERCURY RECOVERY

After crushing of fluorescent light lamps, mercury recovery is often the next step taken in the recycling process. Most commonly, crushed lamps that are not landfilled undergo retorting or roasting.[1] These processes recover mercury by distillation (i.e., heating the material to vaporize the mercury and subsequently collecting it by cooling the offgas stream to condense liquid elemental mercury). Different versions exist, but in each, the material is heated to vaporize the mercury and recover it as a liquid. This can be accomplished in closed vessels (retorts) or in open-hearth furnaces, ovens, or rotary kilns (roasting).[1] Recovery of the vaporized mercury can be done with condensers and separators or with a venturi scrubber and decanter, followed by an air pollution control system.[1]

Retorting generally gives higher recovery rates than does roasting, and is also well-suited to wastes containing volatile forms of mercury (e.g., elemental, oxidized species). Thus retorting is generally the recovery method of choice for fluorescent lamps.[1]

Generally, the mercury-containing wastes are placed in a retort, and heated for four to twenty hours to a temperature above the boiling point of mercury (357°C) but below 550°C.[1] Vaporized material from this process is condensed in the scrubber or condenser, and then it is collected in a collector or decanter. This collected mercury may require additional treatment, such as nitric acid bubbling, to remove impurities.[1]

The potential emission points from a retort process include the condenser or scrubber vent and the handling areas for waste feed and recovered mercury.[1] Fugitive emissions from these points may be controlled by enclosing the entire system and operating it under negative pressure, similar to the system at MRS AB, as previously described. There may also be mercury emissions from scrubber wastewater. Final treatment of these wastes has been shown to be achieved with activated carbon, with the used carbon being disposed at a hazardous waste landfill.[1]

5.0 DISCUSSION AND CONCLUSIONS

A typical four-foot fluorescent lamp contains about 41 mg of mercury, although this value is expected to decrease to 27 mg by 1995. The maximum measured concentration is found in the white phosphor powder on the inside surface of the glass. The vapor in the lamp would contain about 0.04 mg of mercury at room temperature (assuming the vapor is saturated with mercury).

The amount of mercury emitted from a spent lamp depends on the way the lamp is handled after it is changed. In one extreme, used lamps are simply broken into a dumpster and transported to the landfill in a garbage truck. It is assumed that all of the lamps in garbage trucks are broken and that vaporized mercury in these trucks finds its way to the atmosphere.[1] In the other extreme, the discarded lamps are packed in corrugated containers from which the new lamps were taken and are then loaded into enclosed vans or trailers for removal to a landfill. In this case, it is assumed that few lamps are broken and practically all of the mercury is retained in the landfill.[1]

In any case, recovery of the mercury in lamps appears to be desirable, in that the net amount of mercury ultimately released to the environment is reduced. The recovery process begins with the crushing of lamps to extract the white phosphor powder, which contains the bulk of the mercury. This powder is then put into a mercury retort to recover elemental mercury.

Lamps can be crushed either by a mobile crushing unit at the point of collection, or by a centralized stationary crushing unit. Both of these operations generally use small lamp crushing units which fit on the top of a 55 gallon collection drum. Industrial hygiene measurements around these drum-mounted crushers have shown that, even in a well-covered crusher, some mercury escapes from the lamp feed tube, causing concentrations of about 0.3 mg/m^3. This is well in excess of the OSHA limit of 0.05 mg/m^3.

Two well-controlled crusher systems were identified. Both of these use a vacuum collection system to prevent release of mercury from the lamp feed system. In both cases, the air is passed through a cyclone, a HEPA filter, and a carbon adsorber before being exhausted. The cyclone removes glass particles; the HEPA filter removes the phosphor powder, which contains most of the mercury; and the carbon adsorber captures mercury vapor. Typically, depending upon the specific operation and the degree of mercury contamination, the glass particles, HEPA filters, and carbon adsorbers are either processed to recover the mercury or disposed of in a hazardous waste landfill.

These controls reduce mercury levels near the crusher to well below the 0.05 mg/m^3 OSHA limit. This implies an emission reduction of at least 90 percent. Table 5 compares calculated and measured mercury emissions and concentrations from different crushing systems.

Table 5: Comparison of Calculated and Measured Emissions from Different Crushing Systems

	Resulting Mercury Concentration (mg/m^3)	**Estimated Emissions**	
		(mg/min)	**(mg/lamp)**
Amount of mercury in the vapor in a lamp (4 foot) prior to breakage (for comparison)	----	----	0.04[a]
Simple covered system with no add-on control	0.3[b]	----	----
MRS	<0.05[c]	0.2-10[c]	0.003-0.16[d]
Mercury Technologies	<0.05[c]	0.14-7[c]	0.002-0.117[d]

[a]Mercury in the vapor phase, calculated based on the vapor pressure of elemental mercury.
[b]Measured five feet from crusher.
[c]Rough estimate using the reported air flow rate and typical exhaust characteristics from a carbon adsorber controlling mercury vapor emissions.
[d]Calculated using the reported rate of lamp-crushing.

6.0 REFERENCES

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