Environmental Assessment and Risk Analysis Element

Research Project Summary

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Release of Mercury From Broken Fluorescent Bulbs

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Abstract

Mercury is a persistent, bioaccumulative toxin. The primary human exposure is from ingestion of fish contaminated with methyl mercury. However, exposures to elemental mercury vapor and mercury compounds via inhalation and dermal contact may also occur. Like many products, fluorescent bulbs contain mercury. Estimates of the amount of this mercury released when the bulbs are broken, which generally happens when the bulbs are discarded, have varied widely. A new method was developed to measure mercury released from broken bulbs. It was found that between 17% and 40% of the mercury in broken low-mercury fluorescent bulbs is released to the air during the two-week period immediately following breakage, with higher temperatures contributing to higher release rates. One-third of the mercury release occurs during the first 8 hours after breakage. Many fluorescent bulbs contain more mercury than the low-mercury bulbs tested; a typical bulb discarded in 2003 might release between 3 and 8 mg of elemental mercury vapors over two weeks. Since about 620 million fluorescent bulbs are discarded yearly in the U.S., discarded bulbs could release approximately 2 to 4 tons of mercury per year in the U.S. Airborne levels of mercury in the vicinity of recently broken bulbs could exceed occupational exposure limits.

Introduction

Mercury exists in elemental form (Hg^0), and is found in numerous chemical compounds, including toxic, bioaccumulative, methylated species, such as methyl mercury ($HgCH_3^+$). Many forms of mercury, including elemental, are volatile enough so that a significant portion can exist in the gaseous state. All forms of mercury are toxic to humans and can lead to a variety of nervous system effects. Any form of mercury in the environment is cause for concern because a portion of this mercury is converted to methyl mercury, which accumulates in fish to levels that can harm humans and wildlife that consume the fish.

Recent studies have shown that much of the human release of mercury to the environment is from coal combustion and the incineration of wastes.[1,2] Use of mercury in some industrial processes, especially the production of chlorine, has also released much mercury.[3] The New Jersey Mercury Task Force has identified the manufacturing of iron and steel as a source of mercury emissions.[4] The recycled metals used as feedstocks by many iron and steel manufacturing plants appear to be contaminated with mercury found in switches and other measuring and electrical apparatus that end up in scrap metal. Other product-related releases of mercury occur; discarded fluorescent bulbs are an example of a product that, upon disposal, can release mercury to the environment.

In fluorescent bulbs, mercury is used to convert electrical energy to radiant energy in the ultraviolet range, which is then re-radiated in the visible spectrum by the "phosphor" compounds that coat the inside of the bulb. The average mercury content of a 4-foot-long bulb manufactured today is approximately 12 mg. Bulbs manufactured in the mid-1980s and earlier contained 40 mg or more. Low-mercury bulbs, containing 4 mg or less, are currently produced by at least one manufacturer. A typical fluorescent bulb discarded today is likely to contain an average of approximately 20 mg mercury.

How much mercury will be released from broken fluorescent bulbs has been the subject of some debate. The amount released appears to be a function of a number of factors, especially temperature.

The exact fate of mercury within fluorescent bulbs has not been well described. As the bulb ages, an increasing amount of elemental liquid mercury is converted to solid mercury compounds (principally HgO). According to industry reports, the quantity converted to HgO is between 1 and 4 mg in typical bulbs at the end of the bulb's rated life and a certain amount of the elemental mercury originally present will bind to the glass as the bulb ages.[5]

EPA has estimated that 6% of the mercury in broken bulbs is released to the air.[6] An industry report states that only about 1% of the mercury in the bulbs is released during disposal and recycling operations.[7] Release of 20% to 80% of the mercury in discarded bulbs has been suggested by a study for Oak Ridge National Laboratory by Lindberg et al.[8]

In this project, an experiment was conducted to actually measure the amount of mercury released from broken low-mercury fluorescent bulbs. The experiment was designed to mimic a typical solid waste disposal scenario, in which a discarded bulb was broken during handling and then stored in an uncovered container, such as a dumpster or trash can, for a period of time before final disposal.

Methods

Burned-out low mercury fluorescent bulbs (Philips 4-foot Econo-watt F40 CW/RS/EW, 0 8E) were broken in the bottom of a new 32-gallon plastic barrel. The contained space was sampled at various intervals to determine the release rate of elemental mercury vapor. These bulbs are reported to contain either 4.4 mg or 4.7 mg of mercury, depending on exact date of manufacture.[9] It was assumed that 4.55 mg was the amount of mercury in the bulbs broken in this experiment.

A Jerome 411 Gold Film Mercury Vapor Analyzer[10] was used to detect mercury vapor released from the broken bulbs. This instrument detects elemental mercury vapor. Precision of the meter is +5% at 0.107 mg/m^3 with a range of 0.000 to 1.999 mg/m^3.

A half-inch diameter port was installed in the side of the barrel, through which a half-inch outside diameter rubber probe connected to the analyzer's intake port was inserted. The port was kept closed when the probe was not inserted.

The experimental procedure consisted of the following steps:

1) The mercury concentration inside the barrel was recorded. At the start of the experiment, the concentration was typically non-detect. (Normal atmospheric background levels, which are <10 nanograms per cubic meter (ng/m^3), are below the detection limit of the Jerome 411.)

2) One or more spent fluorescent bulbs were broken and crushed inside the barrel, and the barrel was immediately covered. The lid/barrel interface area was sampled with the meter. Such sampling typically resulted in non-detect levels (with several readings in the range of 0.001 to 0.004 mg/m^3), revealing that a significant amount of mercury vapor did not escape from the closed container.

3) After a period of time, which varied during the course of the experiment from 2 minutes to over 10 hours, the concentration of mercury vapor inside the barrel was recorded by inserting the sampling probe through the port in the barrel.

4) After the concentration was recorded the lid was removed to allow the contained mercury vapor to escape to the outside atmosphere. It was found that approximately 5 minutes was long enough to allow most of the mercury vapor inside the barrel to escape.

After this purging, the probe was inserted down into the barrel from the top, the post-purge concentration recorded, and the barrel immediately covered with its lid. Steps 3 and 4 were repeated numerous times over several days.

Results

Results for experiments run at three different temperatures were adjusted to account for the fact that some of the mercury released immediately after breakage already existed within the tube as vapor. The amount of mercury released was translated into an amount released per time period, and then into a release rate, in grams per hour. A chart of release rate vs. time for three different temperatures appears as Figure 1. Equations describing the relationship of release rate to time were found using curve-fitting software, and the areas under the curves were integrated to develop an estimate of the total amount of mercury released per given time period. These data manipulations are described in detail elsewhere.[11]

The maximum amount of time broken bulbs are likely to exist in the waste management system was judged to be two weeks (340 hours), representing the time between trash pick-ups and allowing for several days to a week at transfer stations or other intermediate storage areas. The cumulative amount released from 0 to 1 hours, from 0 to 2 hours, from 0 to 3 hours, etc., was then calculated as described above. Cumulative total releases up to 340 hours at three different temperatures are shown in Figure 2.

Experiments were also run with other brands of bulbs, although the results are not reported here because the method had not been refined. However, it is clear from the results of these experiments that the amount of mercury released is greater with bulbs that contain more mercury.

Conclusions and Recommendations

It was found that the mercury release rate varies proportionally with temperature, which was expected because of the greater volatility of mercury at higher temperatures. Also, the release rates are consistent with the range reported by Lindberg et al.[12] The results are also consistent with a preliminary analysis of data collected during the operation of a commercial bulb-crushing system in Illinois, which suggests that approximately 18% of the mercury in fluorescent bulbs is released over an 8-hour period during crushing operations.[13]

This study indicates that at temperatures ranging from 40° to 85° F, between approximately 17% to 40% of the mercury contained in a broken fluorescent tube will volatilize during a two-week period, with higher volatilization rates corresponding to higher temperatures. One-third of the mercury released will occur during the first 8 hours after breakage. A typical discarded bulb might contain approximately 20 mg of mercury, and would thus release between 3 and 8 mg over two weeks.

The pattern of emission, with an initially rapid release declining to a slowly decreasing rate, suggests that at least some of the mercury in the bulbs is in a form that can quickly vaporize, such as tiny droplets of elemental mercury. If this is the case, agitation of the broken pieces would speed up the release. The slowly decreasing rate that

Figure 1

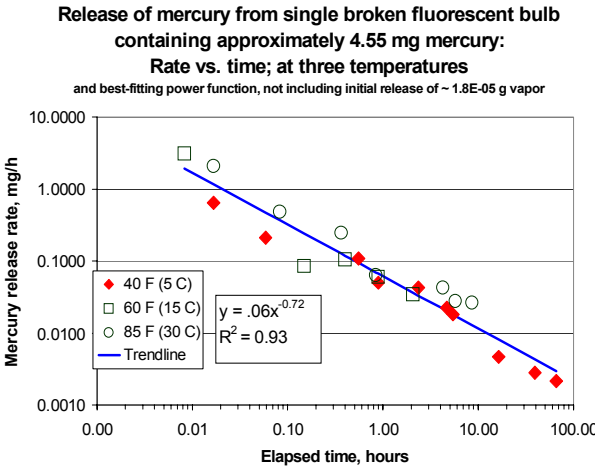
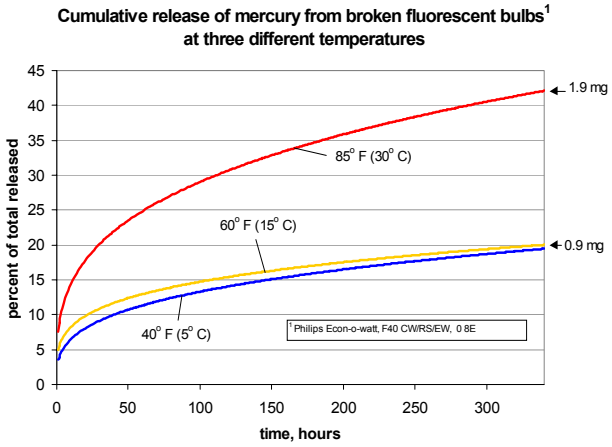


Figure 2



appears to result after the first 8 hours or so may reflect the gradual release of forms of mercury less subject to volatilization, such as mercury adsorbed to surfaces within the bulb. It is also possible that the decline in emission rate reflects oxidation of mercury. If significant amounts of mercury are oxidizing over time, mixture of broken bulbs with other wastes might reduce the mercury emission rate.

Approximately 620 million fluorescent bulbs are discarded yearly.[14] Despite the existence of recycling programs, it is estimated that only about 20% of discarded bulbs are recycled nationally.[15]

It is probable that most of the bulbs that are not recycled are broken during disposal. Extrapolation of the results of this study suggests that discarded fluorescent bulbs release approximately 2 to 4 tons/year of mercury in the U.S.

However, use of the results of this study to estimate mercury emissions from broken bulbs must note several sources of uncertainty. Some uncertainty stems from variations in bulb mercury content and waste management procedures. Other uncertainties exist due to the experimental and calculation methods. The various uncertainties are described in detail elsewhere. [16]

Another aspect of these findings should be noted. This study suggests that elevated airborne levels of mercury, exceeding EPA's reference concentration of 300 ng/m^3, can exist in the vicinity of recently broken bulbs. Potential occupational exposure may exist for sanitation workers and employees involved in recycling fluorescent bulbs in the presence of broken bulb residue.

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