Mercury Exposure From Broken Compact Fluorescent Lamps: A Risk Assessment Using the Alliance For Risk Assessment (ARA) Collaborative Model

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Abstract

Compact fluorescent lamps (CFLs) are more energy efficient and are being promoted as an eco-friendly replacement for incandescent lamps, but they contain mercury. Internationally, concerns have been raised about mercury exposure following breakage. Exposures from such breakage include inhalation or dermal exposure, potentially causing health effects. The New Zealand Ministry of Health approached the Alliance for Risk Assessment seeking a screening level risk characterization of mercury release.

Risk to infants and adults was evaluated based on two exposure scenarios: CFL breakage in a room with no ventilation and no clean-up, and CFL breakage in a room with adequate ventilation and clean-up. Concentration data from a study by Stahler et al. (2008) were compared to human toxicity benchmarks to calculate hazard quotients. For the no clean-up scenario, hazard quotients were less than one, an unlikely health risk. When the room was ventilated and the CFL was cleaned-up, mercury concentrations were lower. A review of release scenarios, along with duration-adjusted toxicity benchmarks, indicates that few releases produce levels of concern, but some scenarios can exceed risk targets and require further study. Uncertainties in the screening characterization include assumptions about room size, ventilation, age of bulb, the distribution of mercury in the room, and also the choice of the toxicity benchmarks used to development the hazard quotients.

This project was conducted under the auspices of the Alliance for Risk Assessment (ARA), a collaboration of stakeholders representing government, academic, industry, environmental and consulting perspectives. As an ARA project, this assessment was vetted for scientific relevance and was conducted by an independent, nonprofit organization, using state-of-the-science chemical risk assessment methods to protect public health. ARA risk assessments are performed in a transparent manner, and made publically available upon completion.

Mercury and Toxicity

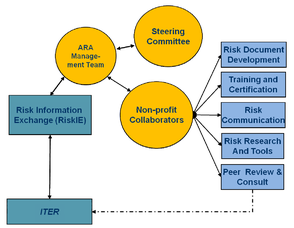
- Inhalation of mercury vapor is the key exposure pathway as 80-97% of inhaled elemental mercury is absorbed into the body through the lungs (WHO, 2003).
- Once in the body, because mercury is lipid soluble, it can cross biological membranes including the blood-brain barrier and the placenta, and can accumulate in the brain and kidneys (HPA, 2006).
- The central nervous system is the most sensitive target for exposure to mercury vapor, and adverse effects have been associated with low level chronic exposure.
- Populations sensitive to mercury exposure include infants, pregnant women and fetuses, children under the age of six, and people with kidney

Alliance for Risk Assessment Collaboration

This project was conducted under the auspices of the Alliance for Risk Assessment (ARA), a collaboration of stakeholders representing government, academic, industry, environmental and consulting perspectives. Given a limited supply of time, resources, and know-how, public health protection is an effort that requires cooperation, organization, and prioritization. The Alliance help focus these resources to increase the output of risk values.

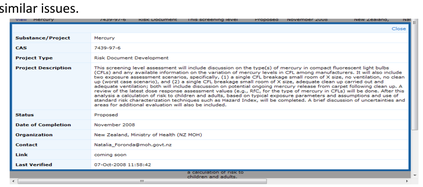
The ARA works toward this goal by striving for:

- **Improved communication among groups**
- **Transparency in development of products**
- **Harmonization and consistency in risk assessments**
- **Shared costs and human resources**



Risk Information Exchange

Seeking Alliance assistance on this project, a project proposal was submitted to the Risk Information Exchange (RiskIE, www.allianceforrisk.org/RiskIE.htm), a free database for tracking the in-progress risk assessment and toxicological work of groups around the world. As seen below, details of this project posted to RiskIE serve as an announcement to the risk community of work underway. By providing a centralized source of project information, RiskIE helps bridge communication gaps among different organizations, and allows groups to identify others working on similar issues.



This project was submitted to the Risk Information Exchange in October of 2008. The listing is publicly available at www.allianceforrisk.org/

ARA Steering Committee

A project submitted to the Alliance, is first reviewed by the ARA Steering Committee, a balance of Federal, State, and Tribal governments, Environmental NGOS and non-profits, and Academia. Current Steering Committee members include:

- Anita Meyer, United States Army Corps of Engineers
- Barbara Harper, Confederated Tribes of the Umatilla Indian Reservation
- Bette Meek, University of Ottawa
- Edward Ohanian, United States Environmental Protection Agency
- Michael Dourson, Toxicology Excellence for Risk Assessment (TERA)
- Michael Honeycutt, Texas Commission on Environmental Quality (TCEQ)
- Phil Wexler, National Library of Medicine (NLM)
- Ruthann Rudel, Silent Spring
- William Hayes, State of Indiana

The Steering Committee reviews projects for mission relatedness, impact to the broader risk assessment community, and helps identify relevant work being conducted by groups in their respective sectors. In this case, Steering Committee members identified several of the key of references upon which this study was based.

Exposure Scenarios

We considered two exposure scenarios for this assessment.

A single CFL is broken:

- **Scenario 1:** in a small room that has no ventilation and no clean-up is performed. Floors are made of wood.
- **Scenario 2:** in a small room with adequate clean-up and adequate ventilation. Three types of flooring used – wood flooring, short pile carpet and shag carpet. Ongoing mercury release from carpeting following clean-up is monitored.

Key Data: Stahler et al. 2008

The most comprehensive study of mercury exposure following breakage of CFLs was undertaken by the Maine Department of Environmental Protection (Stahler et al., 2008).

- The aim of the study was to inform guidance on appropriate clean-up procedures following breakage of CFL.
- The study investigated a range of scenarios including clean-up method, type of lamp and floor covering (hardwood, short nap carpet and shag pile carpet).
- For each scenario, a new CFL was broken on a painted mesh cloth (hardware cloth), placed over a piece of floor covering, and placed inside a cardboard box.
- The resulting mercury vapor concentrations were measured at one foot (0.3 m) and five feet (1.5 m) sampling heights directly above the breakage site. The five-foot sampling height was chosen to represent the breathing zone of adults and the one-foot sampling height to represent the breathing zone of infants and toddlers.

Table 1. Averaged Data for Scenario 1

Averages mercury concentration for the three trials of Maine Scenario S1 (unvented, "Brand A" 14wt, no clean up) (extracted from Stahler et al. (2008).

	Ave of Max (ng/m^3)	RSD[a] of Max (ng/m^3)	15 min avg. (ng/m^3)	15 min RSD	30 min avg. (ng/m^3)	30 min RSD	1 hr avg. (ng/m^3)	1 hr RSD
5 feet	546	72.4	193	50	186	50	169	44
1 foot	22,244	59.5	775	29	572	36	404	48

a. RSD = Relative Standard Deviation is computed as follows:
RSD = 100 X (Standard Deviation of Trial averages)/(Average of Trial averages)

Table 2. Data for Scenario 2

Average concentrations in ng/m3 for the three trials of Maine Scenario S2 to S6 (extracted from Stahler et al. (2008).

Scenario (Intake)	Avg. of Maxa (ng/m3)	RSD of Maxb	15 min avg. (ng/m3)	15 min RSD	30 min avg. (ng/m3)	30 min RSD	1 hr avg. (ng/m3)	1 hr RSD
All (5-ft)	549	48.1	176	33.4	132	41.7	90	57.1
All (1-ft)	11,880	77.0	42.5	52.1	266	63.3	159	82.7

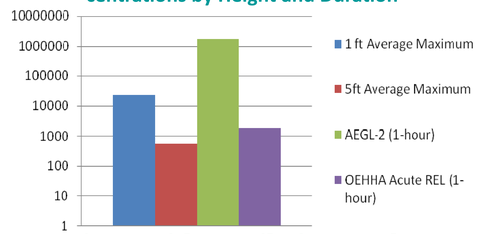
a RSD = Relative Standard Deviation is computed as follows: RSD = 100 X (Standard Deviation of Trial (averages)/(Average of Trial averages) b Three trials were run for all six scenarios. An additional trial was run for scenario 3. Two trials, S2T1 and S3T1 (one foot intake) did not include 1 hour average results due to shortened runs.

Key Considerations:

- Mercury concentrations are higher the closer one is to the broken CFL; concentrations are not uniformly distributed in the room;
- This brand of CFL contained 1.23 – 2.7 mg/kg-day of mercury; other bulbs might have greater or smaller levels;
- These CFLs were new bulbs and likely have greater mercury vapor available for immediate release versus spent bulbs;
- For Scenario 2, three types of flooring used – wood flooring, short pile carpet and shag carpet. The results differ with the type of flooring.

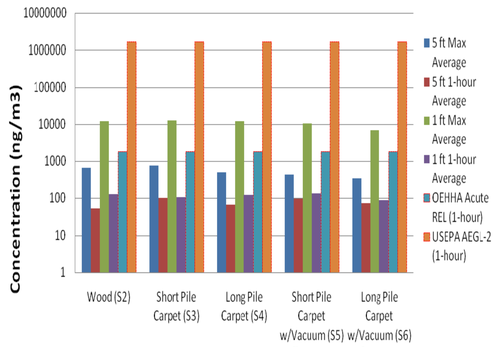
Scenario 1: No Ventilation or Clean-Up

Figure 1. The Average Maximum Mercury Vapor Concentrations by Height and Duration



Scenario 2: With Ventilation & Clean-Up

Figure 2. Average Mercury Vapor Concentrations by Height and Durations



Dose-Response Information

There are several agencies that have developed human health toxicity values for exposure to mercury. Table 3 lists the values that are relevant to exposure to elemental mercury va-

Table 3. Human Health Toxicity Values

Agency	Type of Exposure	Value	Year	Species	Critical effect	NOAEL/LOAEL	UF[b]	Principle Study
NAC	AEGL2[a] 10 min	3.1 mg/m^3 (3,100,000 ng/m^3)	2008	Rat	absence of lesions in pregnant rats	NOAEL of 4 mg/m^3 for 2 hours/day for 10 days	3 (3A, 1H)	Morgan et al. 2002
	AEGL2 30 min	2.1 mg/m^3 (2,100,000 ng/m^3)	2008	Rat	absence of lesions in pregnant rats	NOAEL of 4 mg/m^3 for 2 hours/day for 10 days	3 (3A, 1H)	Morgan et al. 2002
	AEGL2 60 min	1.7 mg/m^3 (1,700,000 ng/m^3)	2008	Rat	absence of lesions in pregnant rats	NOAEL of 4 mg/m^3 for 2 hours/day for 10 days	3 (3A, 1H)	Morgan et al. 2002
OEHHA	Acute REL (1-hour)	0.0018 mg/m^3 (1800 ng/m^3)	1999	Rat	CNS disturbances in offspring	LOAEL of 1.8 mg/m^3, NOAEL not observed	1000 (10L10A 10H)	Danielsson et al. 1993

a. Note that AEGLs also incorporate a time adjustment. b. Uncertainty factors are used to account for extrapolation or uncertainty in several areas. "L" accounts for extrapolation from a LOAEL to a NOAEL; "H" accounts for inter-human variability; "A" accounts for extrapolation from experimental animals to humans.

Hazard Index

To evaluate the safety of a particular exposure level to a non-carcinogenic hazard, the hazard index concept is generally used. The index is computed by dividing the exposure estimate by a risk value corresponding to the duration of exposure. Risk values were chosen primarily to match the exposure duration of interest.

Table 5: Hazard Index (HI) Scenario 1

Agency Risk Value[1]	Agency Value (ng/m^3)	Avg. of 1 ft Max (HI)	1ft 1 hr Avg (HI)	Avg. of 5ft Max (HI)	5ft 1hr Avg (HI)
AEGL-2 (10 minutes)	3,100,000	<0.01	NA	<0.01	NA
AEGL-2 (30 minutes)	2,100,000	0.01	NA	<0.01	NA
AEGL-2 (1-hour)	1,700,000	NA	<0.01	NA	<0.01
OEHHA Acute REL (1-hour)	1800	NA	0.2	0.30	0.09

1. See Table 1 for Scenario 1 max/avg values at 1/5 ft used to calculate HI.

For Scenario 1, none of the average maximum concentrations exceed the AEGL-2s (10, 30, or 60 min at 3.1 mg/m^3, 2.1 mg/m^3, and 1.7 mg/m^3 respectively) or the OEHHA acute REL (1-hour at 1800 ng/m^3). The 1 ft average concentrations exceed the 300 ng/m^3 level that represents one estimate of a "safe" level for a lifetime of exposure (in this case EPA's RfC) (not shown in Figure 1).

Areas of Uncertainty

- Mercury concentrations are not uniformly distributed in the room;
- The brands of CFL tested contained generally from 1 to 3 mg of mercury, other bulbs might have greater or smaller levels;
- These tested CFLs were new bulbs and likely have greater mercury vapor available for immediate release versus spent bulbs;
- Stahler et al. (2008) illustrated that variability exists between trials within a scenario and between scenarios. This variability was not so great, however, as to affect the overall results.
- Choice of the dose-response assessment value used in the development of the hazard indices. Choices of AEGLs of various durations for comparison with the averaged maximum 1 ft and 5 ft exposures, and of the established 1-hour REL from OEHHA for comparison with the average 1-hour exposures were reasonable based on exposure duration.

Conclusions

A hazard index greater than 1 suggests the need to examine exposure scenario more closely as the exposure is approaching the "safe" dose. For the no clean up, Scenario 1, all hazard indices were less than one, some well below 1. This demonstrates that even without adequate ventilation (an open window in the case of Scenario 2), the average one-hour concentrations are not a health risk, even if the broken bulb was not cleaned up immediately. Using concentrations appropriate for Scenario 2 (summarized in Table 4), hazard indices are approximately equal to or less than those calculated for Scenario 1. This indicates that adequate ventilation and clean up results in lower mercury concentrations, and that like results from Scenario 1, human health risk is unlikely.

This was an Alliance for Risk Assessment (ARA) project, meaning it was conducted in an open and transparent manner, with the approval of stakeholders with governmental, tribal, environmental and academic interests. As with all projects of the Alliance for Risk Assessment, this report is available online at www.allianceforrisk.org/

Acknowledgements

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Full references are available on request (Willis@tera.org)

Stahler, D., Ladner, S., Jackson, H. (2008) Maine Compact Fluorescent Lamp Study. Maine Department of Environmental Protection. Maine Department of Environmental Protection. Available at: http://maine.gov/dep/rwm/homeowner/cflreport.htm