

Compact Fluorescent Lamps (CFL) and Mercury

Review of the Maine Compact Fluorescent Lamp study (February 2008)

For the Department of Environment, Water, Heritage and the Arts

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19 December 2008

CONTENTS

Glossary of Terms and Abbreviations	3
Executive Summary	5
1. Introduction	6
2. Key findings of the Maine report	6
3. Toxicology of mercury	9
4. Toxicological basis for interpretation of the Maine results ...	10
5. Mercury exposure from CFLs in context with other sources ..	11
6. Other acute exposure scenarios and standards	13
7. Discussion and conclusions	14
8. Recommendations.....	16
9. References	17
Appendix A: Terms of Reference	19

GLOSSARY OF TERMS AND ABBREVIATIONS

ATSDR	Agency for Toxic Substances and Disease Registry – an agency of the US Department of Health & Human Services which compiles reports and summaries of hazardous environmental chemicals
CFL	Compact Fluorescent Lamp
EPHC	Environment Protection & Heritage Council
Hg	elemental (metallic) mercury; the oxidised valence states are designated as Hg^+ (mercurous) and Hg^{++} (mercuric)
HHRA	Human Health Risk Assessment – the process of assessing risks to human from a defined chemical exposure scenario
IRIS	Integrated Risk Information System – a database compiled by the US EPA which summarises toxicological information on chemicals and provides some estimates of safe levels of exposure
LOAEL	Lowest Observable Adverse Effect Level – the lowest dose level in a study (usually with experimental animals) where the incidence of adverse effects is clearly higher than in controls
Maine Report	<i>Maine Compact Fluorescent Lamp Study</i> from the Maine Department of Environmental Protection, February 2008
MAAG	Maine Ambient Air Guideline – the air quality guideline for elemental Hg ($0.3 \mu\text{g}/\text{m}^3$) used as a benchmark for exposure in the Maine Report
MeHg	Methylmercury – an organic form of mercury for which seafood is an important dietary source for humans
NOAEL	No Observable Adverse Effect Level – the highest dose level in a study (usually with experimental animals) where the incidence of adverse effects is no different from that in controls
OEHHA	California Office of Environmental Health Hazard Assessment – an authority which has set a short-term (1 hr) Reference Exposure Level (REL) at $1.8 \mu\text{g}/\text{m}^3$ for Hg
OSHA	U.S Occupational Safety & Health Administration; the authority which has set a permissible ceiling occupational exposure limit of $100 \mu\text{g}/\text{m}^3$ for Hg
RfC	Reference Concentration – a US EPA guideline which establishes an estimate of exposure by the inhalation route over an entire lifetime which is unlikely to be associated with adverse health effects; for Hg the RfC is $0.3 \mu\text{g}/\text{m}^3$

TWA	The (8 hr) Time-Weighted Average used to assess occupational exposures
UF	Uncertainty Factor – applied to the NOAEL or LOAEL to derive the RfC
µg	microgram; equivalent to 0.001 milligram (mg) or 1000 nanogram (ng); in this report, while figures in original reports may have been reported in one or other of these units, they have been converted to µg for consistency
US EPA	United States Environment Protection Agency

EXECUTIVE SUMMARY

Replacement of conventional incandescent light globes with Compact Fluorescent Lamps (CFLs) is a measure designed to improve energy efficiency because of their relatively longer lifespan and lower energy consumption. However CFLs, like the predecessor linear fluorescent tubes which have been in use for decades, contain small amounts of elemental mercury (Hg) which may be released in the event of breakage.

Elemental (or metallic) mercury is toxic to the nervous system. There is a substantial body of evidence which shows that long-term exposures in occupational settings (e.g. workers in plants producing chlorine products; dentists and their clinic staff) can cause subtle behavioural and sensory changes consistent with brain damage. It has also been known that excessive exposure to an organic form of mercury in the diet (methylmercury, mainly from fish) can also result in neurobehavioural impairments in adults and children. Based on this knowledge, women have been advised to limit their fish consumption patterns when pregnant, to avoid damaging the developing brains of their babies.

Another source of exposure to elemental Hg is from dental fillings using mercury amalgam. The possible health impacts from this dental source have been controversial, but recent reviews by competent Dental and Health authorities (e.g. the Australian National Health & Medical Research Council) have not implicated this source of Hg exposure as posing a sufficient health risk to require any remedial actions.

The potential for a broken CFL to contribute a significant amount of Hg exposure in a domestic setting was brought to attention of regulatory authorities by a study from the Maine Department of Environmental Protection, in February 2008. The purpose of this present report is to analyse the outcomes of the *Maine Study* and address issues relating to cautionary practices to be observed should it become necessary to clean up the debris from a broken CFL.

The *Maine Study* measured the amount of Hg vapour released from broken CFLs under various conditions, including some with and without adequate ventilation and/or cleanup of the area. The methodology of the *Maine Study* was quite rigorous and it did show that air levels of Hg could exceed, at least for a short time and in some cases by a substantial amount, published Maine air quality guideline values for elemental mercury. The air guidelines against which the *Maine Study* air monitoring results were compared are designed to protect the public from continuous Hg exposure over a substantial part of their lifespan. It is unlikely that short-term exposures prior to, during or after cleaning up the broken CFL material could constitute a health risk, because of the conservatism built into the risk assessments. However, this report does highlight a need for Australian regulatory authorities to consider developing more appropriate health-based guidelines to address such short-term Hg exposure scenarios.

Australian regulatory authorities have considered it prudent to frame cleanup guidance which minimises the Hg exposure potential associated with a CFL breakage. This guidance is pragmatic, and mirrors to a large extent, the guidance developed by the Maine and US EPA authorities and guidance which has long been applied to cleanup of mercury spills from other sources. However, it stops short of recommending disposal of contaminated carpets or specific warnings directed towards pregnant women. It is my view that the data from the *Maine Study* do not support the need for such specific additional guidance.

1. Introduction

The Australian government has taken a policy decision to phase out the use of incandescent light bulbs in conventional light fittings in favour of more energy-efficient light globes based on compact fluorescent lamp (CFL) technology. These CFLs use essentially the same technology as linear fluorescent tubes which have been used in both domestic and commercial settings for many years.

Both the compact and linear forms of fluorescent tubes use an amalgam of elemental mercury (Hg), the amount of which varies with the type and manufacturer. Most CFLs are currently being produced with a total Hg content of less than 5mg (5000 µg), compared to a Hg content of around 15 mg in older-style linear fluorescent tubes. Manufacturers are said to be developing CFLs with lower Hg content, in order to address concerns relating to a potential increase in environmental Hg pollution associated with the disposal of the increased numbers of CFLs coming onto the market.

Issues relating to end-of-life cycle disposal of CFLs have fuelled the debate over their introduction. Furthermore, some reports have cast doubts on whether the potential reductions in Hg emissions associated with energy savings from coal-fired power generation (a significant source of Hg pollution in Western countries) will be balanced by the additional Hg released into the environment by disposal of replacement CFLs at the end of their life cycle (Calwell *et al* 2007; Eckelman *et al*, 2008). These end-of-life cycle issues have been marked by the introduction of U.S State-based restrictions on the disposal of all types of Hg-containing fluorescent lights in landfills. In Australia, these same issues are being addressed by the Environment Protection Heritage Council (EPHC) in conjunction with Commonwealth, State and Territory governments. In accordance with the Terms of Reference, the end-of-life cycle matters will not be addressed further in this Report since they will be subject to a separate process.

The main issue which will be addressed here, and one which has been driving much community concern, is the potential for breakage of a CFL to result in a localised release of Hg vapour sufficient to represent a health hazard in a domestic setting. The release of a February 2008 report *Maine Compact Fluorescent Lamp Study* from the Maine Department of Environmental Protection (Stahler, Ladner & Jackson 2008) has resulted in a closer examination of these issues by various regulatory authorities, including the Australian Government.

The Maine Study was apparently prompted by an incident in which a Maine householder incurred a large bill for cleanup costs following breakage of a single CFL (Matson 2008). The high costs were apparently driven by U.S guidelines detailing cleanup and disposal procedures in the event of a CFL breakage.

2. Key findings of the Maine Report

The Maine Report details the outcomes of 45 experimental trials where CFLs were broken, under controlled conditions, in small-medium sized rooms representing typical residential settings. The rooms had floor coverings ranging from carpets to hard surfaces, and the effects of different types of ventilation and cleanup practices were trialled. In each trial, Hg vapour arising from the broken CFL was measured by continuous monitoring (Lumex analysers

sensitive to air levels of $0.002 - 0.02 \mu\text{g}/\text{m}^3$ at heights of 5 ft (adult breathing zone) and 1 ft (infant/toddler breathing zone) for periods up to 4-6 hours.

Separate studies were conducted to assess the residual post-cleanup surface Hg concentrations on wood and carpet flooring surfaces, with and without local agitation, and the amounts of Hg retained in vacuum cleaners used to collect material from the breakage sites.

The methodology used in the Maine Study was appropriate considering its objectives. The inclusion of tests where cleanup of Hg from different types of surfaces, at different times after breakage, and using different commercial brands of CFL provided information on a range of typical CFL breakage and cleanup scenarios. The design was modified during the course of the study when it was realised that venting outside the sealed room of the sampling lines to the Lumex analysers was contributing to a dissipation of the Hg. In subsequent tests, the air from the Lumex analysers was returned to the room.

Peak airborne concentrations of Hg measured in the Maine Study were, in some instances, quite high. The highest recorded air concentration was $54.1 \mu\text{g}/\text{m}^3$ at the 1 ft level and $8.3 \mu\text{g}/\text{m}^3$ at the 5 ft level. These maximum readings tended to dissipate reasonably quickly when the room was adequately ventilated or after cleanup of the broken CFL material.

One possible criticism of the Maine Study design was that the sampling sites were immediately above the site of breakage of the CFL lamps. A more representative sample of the air levels in the room may have been obtained if sampling sites more distant from the site of breakage had been included.

A key objective of the Maine Study was to compare the measured airborne Hg concentrations with the Maine Ambient Air Guideline (MAAG) value of $300 \text{ ng}/\text{m}^3$ ($0.3 \mu\text{g}/\text{m}^3$; more later on the derivation of this value).

The study did show that, despite the very high readings taken soon after breakage, the Hg concentrations fell below the MAAG within 1 hour in 31 of 45 trials at the 1 ft level, and 35 of the 45 trials at the 5 ft level. The average airborne Hg concentration over the first hour was below the MAAG in 27 of the 45 trials at the 1 ft level, and 33 of the 45 trials at the 5 ft level. Not surprisingly, the study showed quite clearly that ventilating the room or prompt cleanup of the broken material, resulted in substantially lower 1 hour averages at either the 1ft or 5 ft levels.

Another finding was that the amount of Hg released was influenced by the type of CFL tested. Five different U.S. CFLs were tested, ranging from 14-26W power output. Since Hg tends to become bound to the CFL phosphor coating over time, all the CFLs tested were new, to maximise the potential Hg release on breakage. While the total Hg content of the CFLs was not specified, some of the variability in the airborne Hg measured was clearly related to the brand of CFL tested. One of the brands tested possibly used a new type of vapour control amalgam technology, and breakage of this lamp (in only one trial) resulted in the lowest airborne Hg concentrations measured.

Some issues around interpretation of the Maine Report findings were:

- **Temperature range:** The Maine study was conducted over a relatively narrow range of indoor temperatures (19-26°C). Since temperature can markedly influence the rate at which elemental Hg volatilises to air, extrapolation of the results to a broader range of Australian climatic conditions may be questionable.
- **Ventilation:** Under the experimental conditions of the study, ventilation of the room (when it was used) was restricted to a single open window. Air conditioning and heating were turned off and ducts sealed. These conditions aimed to duplicate a worst-case exposure scenario. Since room ventilation had such a marked effect on the results, it was translated into emphasis in cleanup guidelines, that rooms be ventilated as soon as possible after a CFL breakage.
- **Air return from the monitoring equipment:** Some of the initial trials were conducted where the air removed via tubes to the Lumex analysers located outside the room was not returned. This unintended ventilation tended to rapidly lower the measured Hg concentrations. In later trials, the Lumex exhaust lines were returned to the room, resulting in more sustained Hg concentrations. The return of scavenged air probably reflects a more realistic exposure scenario where cleanup of the spill is delayed or ineffective.
- **Container testing:** One of the objectives of the Maine study was to evaluate the extent to which vacuum cleaners used in cleanup procedures and containers into which debris was placed for disposal could retain Hg residues, with subsequent potential for re-contamination of living spaces. The study demonstrated that this could occur, and resulted in cleanup guidance being modified to emphasise the importance of using well sealed glass containers and avoidance of the use of vacuum cleaners, especially in unvented areas.
- **Floor surface conditions:** The ability of different flooring materials to retain, and re-release Hg was tested. Not altogether surprising was the finding that carpets (shag and short nap) tended to retain more Hg and were more difficult to decontaminate. Agitation of such surfaces tended to increase the amount of Hg released. Of greater concern was a finding that hard surface timber flooring could retain and re-release Hg even after it appeared visibly clean.
- **Immediacy of cleanup:** Air Hg levels tended to remain higher when cleanup was delayed. The resultant translation into cleanup guidance was to recommend that cleanup not be delayed. However, the Maine report also advised that leaving the room and ventilating it for 15 minutes before initiating cleanup would further minimise Hg exposure potential by allowing air levels to dissipate.

Since the overall conclusions from the Maine Study were that airborne Hg levels could substantially exceed the MAAG for both adults and crawling children for at least short periods of time, there is a need to address the potential significance of these findings to cause adverse health effects. These matters will be address in Sections 3-5 of this Report.

3. Toxicology of mercury

The toxicity of mercury has been extensively reviewed (ATSDR 1999; WHO 1991, 2003; Clarkson, Magos & Myers 2003; Clarkson & Magos 2006; Magos & Clarkson 2006). These reviews have summarised the key findings derived from experimental studies in animals, as well as the substantial body of directly relevant information on toxicity to humans. The human database is derived mainly from studies of occupational exposures (mainly elemental and other inorganic forms of mercury), outcomes associated with major environmental exposures (e.g. Minnamata disease), the potential health effects associated with mercury accumulation in seafood (mainly methylmercury) and, more recently, the controversial issues around whether release of mercury vapour from dental amalgam represents a significant health risk to dentists, their staff or their patients. Most of these studies have focussed on risks from chronic low-level exposures, but there are some informative studies of acute toxicity associated with accidents, intentional exposures (suicide attempts) and medical misadventures associated with inappropriate dosing with medicinal products.

There are substantial differences in toxicity associated with inorganic and organic forms of mercury. Dyspnoea (difficulty with breathing) is often the first observable symptom of an acute intoxication with mercury, along with chest pain, nausea and vomiting. Neurotoxicity (brain damage) and nephrotoxicity (kidney damage) are generally considered to be outcomes of Hg toxicity of most concern, although the most sensitive target organs really depend on the chemical speciation of mercury and the exposure route. Adverse health outcomes tend to be different when exposure has occurred to metallic elemental Hg, or to salts of mercury in mercurous (Hg^+) or mercuric (Hg^{++}) valence states, or to Hg bound in organic compounds (e.g. methyl and ethyl mercury; mercury-based antifungals and preservatives such as thiomersol or phenylmercuric acetate). These different chemical forms of Hg can have quite variable systemic absorption (bioavailability) according to the exposure pathway (oral, inhalational, dermal or parenteral), as well as different patterns of tissue distribution and accumulation, and rate of clearance from the body by various elimination pathways.

For example, metallic mercury is very poorly absorbed when given orally, but up to 80% is absorbed via inhalation of Hg vapours. Mercuric (Hg^{++}) salts such as mercuric chloride are quite corrosive, and acute exposure to high doses is often marked by extensive local tissue damage (e.g. the gut wall if taken orally). Acrodynia (painful extremities) was a common symptom in Pink Disease associated with archaic therapeutic administration of mercurous chloride. Both inorganic and organic forms of Hg have been reported to cause contact dermatitis through a sensitisation mechanism. Irrespective of the exposure route and Hg speciation, it is likely that the ultimately toxic form of mercury in tissues arises from *in situ* oxidation to Hg^{++} and the main form of clearance from the body is via urinary excretion of inorganic Hg^{++} .

Studies on potential Hg-related neurotoxicity have focussed on more objectively measurable effects, such as tremor and finger-to-nose co-ordination, both reasonably sensitive indicators of cerebellar dysfunction. Other studies have addressed some of the more subtle neurotoxic outcomes, such as effects on motor performance and neuropsychological effects such as emotional lability, memory loss, and attention deficits. Wastensson et al (2008) used an eurythmokinometer (EKM) device to measure eye-hand coordination and a diadochokinometer to measure rapid alternating rotation of the forearms as sensitive and reproducible measures of neuromotor function in a cohort of 58 mercury-exposed workers in a

chloralkali plant and 35 unexposed controls. The importance of this study is that, while it demonstrated age- and smoking-related effects on neuromotor functions, it failed to demonstrate any deficits associated with low level elemental Hg exposures - a median urinary Hg excretion of 5.9 µg/g creatinine (range 1.3-25) compared with controls 0.7 µg/g creatinine (range 0.2-4.1). Using the conversion factor derived by Roels *et al* (1987), this equates to an average air Hg concentration of 4.8 µg/m³. The same sensitive techniques have measured significant deficits associated with MeHg and manganese exposures, as well as other neuromotor disease states.

Elemental mercury is the relevant form for exposure associated with CFLs and neurotoxicity is the toxicological endpoint of most concern.

4. Toxicological basis for interpretation of the Maine results

The health-based benchmark exposure used in the Maine Study to interpret the measured airborne Hg levels was the MAAG of 0.3 µg/m³. This value is the same value as the reference Concentration for Inhalational Exposure (RfC) developed by the US EPA (IRIS) and last revised in 2005. The RfC is defined as:

“an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily inhalational exposure of the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime”.

The RfC is derived from a range of occupational studies with humans in which hand tremor, memory disturbances, and autonomic nervous system dysfunction were the critical effects evaluated with respect to elemental Hg exposure. The human studies were complemented to some extent by experimental observations in animals. Most of the key studies on which the RfC is based were conducted in the 1980-90s.

It is important to note that most of key studies used to establish the RfC failed to demonstrate a No Observable Adverse Effect Level (NOAEL) for Hg exposure. The majority of the studies demonstrated an 8-hr TWA exposure LOAEL of 0.025 mg Hg/m³ (equivalent to 25 µg/m³). This is the same value currently accepted as the Australian National Exposure Standard for Hg in the workplace. The exposure estimates which underpin the LOAEL are reasonably robust because the workplace air monitoring data are complemented in some cases by biomonitoring data, where urinary Hg excretion could be correlated with airborne Hg concentrations using conversion factors determined by Roels *et al* (1987).

Using estimates of daily respiratory volumes and adjusting from a working week of 5 days to a continuous exposure period of 7 days/week, this figure was adjusted to 0.009 mg/m³ (9 µg/m³). The LOAEL was further adjusted (divided by 30x UF) to derive the RfC of 3 x 10⁻⁴ mg/m³ (equivalent to 0.3 µg/m³). In this case, the 30x UF incorporates a 10 fold factor for protection of sensitive human subpopulations together with the forced use of a LOAEL rather than NOAEL, as well as an additional 3 fold factor for use of a database which lacked studies on potential developmental and reproductive studies.

While the earlier studies used in deriving the RfC were based on workers exposed in chloralkali plants, and demonstrated LOAELS within a fairly tight range of measured TWAs, some of the later studies examined workers in different occupational settings. For example,

Ngim *et al* (1992) assessed neurobehavioural performance in dentists, where the airborne Hg vapour concentrations were measured by personal sampling badges and confirmed with blood samples. The LOAEL assessed in this study was 0.023 mg/m^3 , which converted to a continuous exposure Human Equivalent Concentration (HEC) LOAEL of $6 \text{ } \mu\text{g/m}^3$. Liang *et al* (1993) measured Hg exposure levels (TWA $33 \text{ } \mu\text{g/m}^3$, urinary Hg excretion average $25 \text{ } \mu\text{g/L}$) in a fluorescent lamp factory and demonstrated some decrements in selected neurobehavioural tests.

Thus all these occupational studies which demonstrated neurobehavioural deficits in workers exposed to Hg identified levels of exposure which were at least one or two orders of magnitude higher than the average Hg levels measured in the Maine study, and were representative of exposures spanning several years.

The Maine Report acknowledges that the MAAG assumes safety based on a lifetime of exposure at or less than $0.3 \text{ } \mu\text{g/m}^3$, while the exposures described in the CFL breakage scenarios were of much shorter duration (in some cases only minutes). However, while acknowledging the MAAG and US EPA RfC values are derived using reasonably conservative assumptions in order to be protective of sensitive human subpopulations, the Maine report nevertheless dwells on the potential for developing organisms (e.g. the foetal brain and developing nervous system in infants) to be susceptible to toxic insults of quite brief duration when encountered during a critical period of brain development.

In this context the Maine Report cites papers by Rice (1996) and Rice & Barone (2000) which outline some of the factors which may make the developing brain more susceptible to neurotoxins. The fact that one of these papers primarily describes differences between rodents and primates in brain development, while the other interprets such differences in neurotoxicological responses to methylmercury (not elemental Hg) in rodents and monkeys, lends little support to the hypothesis that short-term exposures above the elemental Hg vapour MAAG could have deleterious effects.

It is true that a significant focus for human health risk assessment (HHRA) of mercury exposures have been directed towards the risk of impaired neurobehavioural development in children. However, most of this emphasis has been directed towards exposures to methylmercury (MeHg) from food and related sources, particularly where the exposures may have occurred *in utero* as a result of consumption of seafood containing relatively high levels of MeHg. Exposure to MeHg via ingestion of food (particularly seafood) is an exposure pathway likely to be more sustained than inhalational exposure to elemental Hg vapours, and MeHg is a more significant neurotoxin. The Provisional Tolerable Weekly Intake (PTWI) for mercury in fish (mainly in the form of MeHg) was revised down to $1.6 \text{ } \mu\text{g/kg bw/week}$ by the WHO Joint Expert Committee on Food Additives & Contaminants (JECFA) in 2003. Marien & Patrick (2001) surveyed populations who were relatively heavy consumers of a fish diet, and found that many such groups could exceed a Tolerable Daily Intake of total mercury in the range $0.035 - 0.08 \text{ } \mu\text{g/kg bw/day}$.

5. Mercury exposure from CFLs in context with other sources

The amount of elemental Hg exposure likely to be associated with a single broken CFL (the scenario described in the Maine report) is difficult to calculate with any accuracy, since it depends on local air concentrations, breathing rates, and the time over which the

concentrations exceed ambient levels. If one assumes that all of the 5000 µg of Hg contained in a CFL becomes available for inhalation (an unlikely scenario), and assuming 80% retention, a worst-case total exposure could be 4000 µg. A more likely worst-case estimate for an adult, based on the Maine study results, could be based on the following scenario: 50 µg/m³ inhaled over 60 minutes at a respiratory volume of 0.83 m³/hr (20 m³/day; WHO 2003), with inhalational retention of 80%. The amount of Hg retained under such a scenario would be 33 µg. Once the Hg air levels drops below the MAAG of 0.3 µg/m³, (commonly occurring within a matter of minutes in some scenarios), the average intake could drop to as low as 0.2 µg/hr or 4.8 µg/day.

These amounts of exposure should not be regarded as insignificant. They may be contrasted with estimates of total inorganic Hg from all sources, which have been tabulated in various reviews (see Table 1):

Table 1: Estimated average daily intake in µg of inorganic Hg

(source: table 1 from the WHO 2003 CICAD, based on the 1999 ATSDR updated toxicological profile of Hg).

Source medium	Elemental Hg vapour	Other inorganic Hg
air	0.04 – 0.2	0
Food - fish	0	0.6*
Food – non fish	0	3.6
Drinking water	0	0.05
Dental amalgam	1.2 – 27	0
Total	1.2 – 27	4.3

* This figure is inorganic Hg; the intake of organic Hg in the form of methylmercury is likely to be much higher.

The potential for adverse health effects to be associated with Hg vapours arising from amalgams used in restorative dentistry has been a controversial issue. It is not the intent of the present review to revisit this debate. However, the matter was considered in some depth in a review by the NHMRC in 1999 (NHMRC 1999).

The NHMRC did not reach any really strong conclusion about the safety of dental amalgams based on Hg. Rather, the NHMRC report noted that the determination of a safe level of Hg exposure is based on the interpretation of subtle neurotoxic measures in occupational studies, with the application of various uncertainty factors and other adjustments to transform the estimates to a continuous exposure paradigm. The Working Party reported that it had “serious reservations about the quality of data used in such calculations”, and further recommended that “a risk assessment be undertaken in order to establish the safety margins between current intake of mercury from dental amalgam and levels at which adverse health effects are likely.”

Partly because of the relatively high bioavailability by the inhalational route (80% for elemental Hg) compared to the oral route (<0.01%) airborne levels of Hg assume a relatively high significance for total environmental exposure. Ambient concentrations of 0.01 – 0.02 µg/m³ have been commonly reported in U.S. air, but concentrations near point industrial sources such as mines, refineries and agricultural fungicide uses have been reported to be as high as 10 -15 µg/m³. Such industrial sources represent an exposure potential which could be considered comparable to that which could occur in a worst-case CFL breakage scenario.

The NHMRC report provided an estimate of daily retention of elemental Hg from dental amalgams of 0.3 µg for children and 3.5 µg for adults, based primarily on inhalation of Hg vapours. These estimates are lower than the corresponding estimates in the above Table from the 2003 CICAD, but they consistently indicate that dental amalgam could represent the largest single source of elemental Hg exposure in adults. Putting the estimates of Hg intakes which could be sourced from the CFL breakage scenarios described above into perspective, the total elemental Hg exposure from a single broken CFL could reach a comparable value to that from dental amalgam fillings in adults, especially if not properly cleaned up.

6. Other acute exposure scenarios and standards

Since the Maine Report compared the airborne Hg levels with guidelines related to chronic exposures, it may be instructive to examine guidelines and scenarios where short-term exposure has been examined.

The California Office of Environmental Health Assessment (OEHHA) has developed a 1 hr reference exposure level (REL) of 1.8 µg/m³. This level was derived by extrapolation of a LOAEL of 1.8 mg/m³ (equivalent to 1,800 µg/m³) for neurobehavioural toxicity in the offspring of pregnant rats exposed to inhaled Hg vapour for 1 hr/day or 3 hr/day during gestation. The neurobehavioural deficits were assessed 3-7 months after birth of the pups. The 1 hr LOAEL was divided by an Uncertainty Factor of 1000 to derive the REL. The large UF provides a degree of conservatism to the estimate, and it was based on the usual 100x UF used for extrapolation from animals to humans, with an additional 10x because a NOAEL was not established in the study.

Even though the OEHHA REL is based on a rat study rather than human exposure experience, and it is six times higher than the MAAG used as a comparator in the Maine Study, it is possibly a more relevant benchmark since it more closely related to the period of exposure in the Maine Study scenarios. While the **maximum** air levels of Hg in the Maine Study certainly exceeded the REL in most trials at the 1 ft breathing level (but less commonly at the 5 ft breathing level), the 1 hour **average** concentration fell below the REL in all but one of the trials. This was the one trial which also produced the highest maximum air level of 54 µg/m³ at 1 ft.

The OEHHA REL has also been used as a benchmark for assessment of potential health risks associated with Hg spills at two U.S schools (Elgethun 2008). In this assessment, the Hg air levels were 0.32 - 3.0 µg/m³ and 4 - >10 µg/m³ at the two schools. Hg levels measured as headspace arising from contaminated clothing and footwear were 1.5 - 16 µg/m³ clothes and 120 - 500 µg/m³ shoes. The measured levels exceeded the OEHHA REL, but were generally below contemporary US occupational exposure limits (OSHA PEL ceiling limit of 100 µg/m³; NIOSH REL for 10 h exposure of 50 µg/m³). Since there were no pregnant women exposed as a result of the spill, this was taken as reassurance that adverse health effects were unlikely for the staff and students exposed prior to cleanup of the spills, especially since none of those exposed reported any of the characteristic symptoms of acute Hg intoxication (nausea, chest pains, breathing difficulties or cough).

There are no short-term exposure limits for elemental Hg vapours in the Australian National Exposure Standards, but the 8 h TWA ($25 \mu\text{g}/\text{m}^3$) is intermediate between the US EPA RfC and MAAG ($0.3 \mu\text{g}/\text{m}^3$), the OEHHA REL ($1.8 \mu\text{g}/\text{m}^3$), and the higher OSHA PEL ($100 \mu\text{g}/\text{m}^3$), and NIOSH REL ($50 \mu\text{g}/\text{m}^3$), values regulating occupational exposure.

7. Discussion and conclusions

The release of Hg from a broken CFL can result in Hg vapour concentrations in the breathing zone of either adults or children which exceed (at least for a short time) conventional safety guideline values based on occupational exposure scenarios of a much longer duration.

Crawling children may be exposed to higher levels than adults, because their breathing zone is likely to be closer to the site at which Hg is dispersed from the broken CFL. Because neurotoxicity is the adverse health effect of greatest concern in such a scenario, it is likely that very young children and pregnant women may be more susceptible.

For this reason, and because a safe level of short-medium term exposure cannot be determined with precision, cautionary steps should be taken to minimise Hg exposure from broken CFLs. These cautionary steps are relatively more important for pregnant women, but the risks of a short-term exposure appear to include an adequate margin of safety, so that a failure to observe them should not constitute an unreasonable risk or warrant any further restriction on uses of CFLs.

The Maine report suggests that a broken CFL can provide amounts of Hg vapour which could result in inhalational exposure estimates at least comparable to those which might arise in people who have several dental amalgam fillings, or if they live near an industrial point source of Hg emissions. However, the timeframe for exposure arising from a broken CFL is likely to be much shorter than either of the above scenarios.

The precise airborne Hg levels and duration of exposure upon breakage of a CFL will be influenced by a number of factors, including:

- the extent to which the location is effectively ventilated,
- the ambient temperature,
- the nature of the surface on which elemental Hg is dispersed and/or adsorbed,
- the efficiency and speed of any cleanup procedure

Taking these factors into account, regulatory authorities, including the US EPA, and the Maine Department of Environmental Protection have developed pragmatic advice to guide the cleanup of Hg-containing material from broken CFLs. The key elements of this advice are:

- Ventilate the area for 15 minutes before initiating cleanup, but do not leave on any air conditioning or heating equipment which could recirculate Hg vapours back into the room
- Do not use a vacuum or broom to clean up hard surfaces, but scoop broken material into a glass container which can be sealed with a metal lid

- Use sticky tape and/or a damp cloth to wipe clean any remaining glass fragments and/or powders.
- On carpets or fabrics, carefully remove as much glass and/or powdered material using a scoop and sticky tape; if vacuuming of the surface is needed to remove residual material, ensure that the vacuum bag is discarded or the canister wiped thoroughly clean

Comparable cleanup advice relating to broken CFLs is being developed by the Australian Department of Environment, Water, Heritage and the Arts.

The draft Australian cleanup and disposal advice being prepared is as follows:

- Open nearby windows and doors to allow the room to ventilate for 15 minutes before cleaning up the broken lamp. Do not leave on any air conditioning or heating equipment which could recirculate mercury vapours back into the room.
- Do not use a vacuum cleaner or broom on hard surfaces because this can spread the contents of the lamp and contaminate the cleaner. Instead scoop broken material into a glass container which can be sealed with a metal lid
- Use disposable rubber gloves rather than bare hands
- Use a disposable brush to carefully sweep up the pieces
- Use sticky tape and/or a damp cloth to wipe, to wipe up any remaining glass fragments and/or powders
- On carpets or fabrics, carefully remove as much glass and/or powdered material using a scoop and sticky tape; if vacuuming of the surface is needed to remove residual material, ensure that the vacuum bag is discarded or the canister is wiped thoroughly clean
- dispose of cleanup equipment (i.e. gloves, brush, damp paper) and sealed containers containing pieces of the broken lamp in your outside rubbish bin - never in your recycling bin.

The draft Australian advice is pragmatic and suitably cautionary. It includes sensible precautions designed to limit both airborne and skin contact exposures, and includes advice to use cleanup equipment which can be readily disposed to avoid longer-term contamination. It mirrors advice from the Maine Study which suggests that contaminated material from the breakage should be sealed in a glass container sealed with a metal lid, on the basis that the Maine Study showed that Hg vapours could permeate re-sealable plastic containers.

It is appreciated that householders may not have immediate access to all of the recommended cleanup and disposal equipment (particularly a suitably sealed glass container). In the event that such equipment is not immediately available, it is important to emphasise that transfer of the cleanup materials to an outside rubbish bin (preferably sealed) as soon as possible is the most effective way of reducing potential contamination of the indoor environment.

The above cleanup advice is consistent with advice which has been operative for many years to assist with cleanup of Hg spills from devices and/or equipment which contain metallic mercury (e.g. thermometers, manometers). While these types of Hg-containing devices are now less likely to be found in domestic settings, cleanup guidelines for laboratories and other industrial settings where Hg spills can occur are still current and mirror the above guidance.

The Maine Study provided useful information on Hg exposure potential and appropriate cleanup advice in the event of breakage of a single CFL in an enclosed room. While information on potential Hg release under other breakage scenarios would be useful (single and/or multiple CFL breakage during transport, storage or retail sale), such information cannot be readily extrapolated from the Maine Study. Accordingly, this Report makes no comment or recommendations relating to such matters.

The Australian cleanup advice stops short of the Maine Study recommendations relating to CFL breakages on carpets or other porous surfaces, where the Maine DEP advises homeowners to consider removal and disposal of contaminated carpets. The Maine DEP suggests this action as a specific precaution where pregnant women and children may be exposed and it is based on findings that release of Hg vapours can continue from such sources, even after cleanup and especially where the floor surfaced is physically agitated. However, the levels measured in these in the Maine tests were taken within 1 inch of the surface. Since no results were recorded at the 1 ft and 5 ft breathing zone levels, or at more distant points in the room, it is difficult to reconcile the airborne Hg levels emanating from carpets with the air levels measured in the main parts of the study. Accordingly, this reviewer is not convinced that there is a need to recommend disposal of contaminated carpets in the draft Australian guidance.

Perhaps the most significant issue relating to the interpretation of the Maine Study and its relevance for framing advice on risks to human health, is that the airborne Hg levels in the study were compared to the MAAG standard, which is based on an occupational exposure scenario adapted to a lifetime of exposure. It would be useful if regulatory authorities could develop, or endorse, a more suitable short-term exposure guideline for Hg vapour (see Section 6 of this Report).

8. **Recommendations:** That DEWHA

- (i) Consider that the Maine Study provides some reasonable worst-case estimates of potential Hg vapour exposure after breakage of a single CFL on different types of flooring surfaces in a domestic setting, but that the short-term nature of the potential exposure (particularly after effective cleanup) does not constitute a significant health risk to exposed adults (including pregnant women) or children.
- (ii) Continue to develop pragmatic cleanup advice, along the lines of the submitted draft, in order to further minimise both inhalational and dermal exposures during and after cleanup.
- (iii) Request that Australian health regulatory authorities consider the utility of adapted or unadapted Hg occupational exposure guidelines for the health risk assessment of scenarios such as the breakage CFLs in domestic, transport or retail sale settings, and request that they consider developing more appropriate health-based short-term exposure guidelines for Hg.

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Appendix A: Terms of reference for the Review

- (a) Analyse and evaluate available studies (including the *Maine Compact Fluorescent Lamp Study*) relating to risk of exposure to mercury due to breakage and cleanup of compact fluorescent lamps (CFLs) in a range of circumstances including:
- Use in domestic households
 - Storage and sale in retail outlets
 - Transportation of CFL products in the supply chain leading to purchase
 - Occupational handling and use (including maintenance operations)
 - With particular reference to Australian conditions.
- (b) Consider available information on the amount of mercury released due to the breakage of CFLs and based on this information advise on:
- The level of confidence that can be attributed to available test results taking into account the test methods, statistical validity and confidence levels of results.
 - The likely levels of mercury released due to CFL breakage, taking into account variations between CFL types and breakage scenarios, including breakage of new and used CFLs, multiple breakages and cumulative exposure including where relevant to circumstances outlined in (a).
 - The area affected and duration over which significant levels of mercury remain in the breakage area.
 - Variations in the level of exposure to mercury as a result of the environment in which the breakage occurs (including room size, ventilation, temperature variation, and different floor coverings).
- (c) Advise on the significance of the levels of human exposure to mercury due to the breakage of a CFL (including immediate exposure, ongoing exposure without appropriate cleanup and exposure after and during appropriate cleanup) in terms of the risk of significant impacts upon human health including to portions of the population that may be potentially particularly susceptible such as infants, children, pregnant women and foetuses, the elderly and infirm adults. Consider all relevant exposure routes.

Structure and Purpose

- (d) The paper should include an executive summary that accurately communicates the findings of the review, which is to be read by non-experts in the field of epidemiology and or toxicology, therefore requiring the use of plain English.
- (e) A glossary of critical terms and a list or table of abbreviations should be included in the paper.
- (f) The review does not at this stage encompass issues associated with the end-of-life management (disposal methods) of CFLs which is currently under investigation by the Environment Protection Heritage Council (EPHC). These issues may be addressed in a further study at a later date.

Conclusions and Recommendations

- (g) In providing advice on human exposure to mercury and the possible risk to human health, associated with the use of CFLs, provide advice on:
- relevant Australian and or International exposure standards and how they should be applied to CFL breakage scenarios including the relevance of ambient air quality and occupational limits for long term exposure to instances where lamp breakage results in short-lived mercury vapour concentrations.
 - whether available information indicates whether the level of exposure from CFL breakage can exceed relevant exposure standards and the significance of this including whether the level of risk to human health from broken CFLs warrants the provision of advice on the use of CFLs.
 - whether consideration of development of further standards is required and/or further investigation into dose-response relationships and no effect levels is required and feasible.
- (h) Evaluate CFL and mercury advice, including the precautionary cleanup guidelines, made available by the Australian Government Department of the Environment, Water, Heritage and the Arts in the context of available mercury exposure information. Make recommendations on any necessary changes to the advice and cleanup guidelines so as to ensure that:
- adequate and correct information is available to the public on the risks of mercury exposure as a result of CFL breakage; and
 - broken CFL cleanup procedures accurately guide the public on how to reduce the risk of preventable mercury exposure to levels that minimise the risk to human health.
- (i) Identify any gaps in knowledge from the literature review, suggesting the possible impacts this may have on the interpreted data sets. Identify these areas where further information is required and the extent to which this qualifies the conclusions of the review.
- (j) Provide overall conclusions on the level of risk to human health associated with exposure to mercury released from broken CFLs in-situ and in doing so, make any relevant observations regarding the level of risk compared to other toxic household substances, including other sources of mercury.