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QUANTITATIVE RESEARCH

Mercury from crematoriums: human health risk assessment and estimate of total emissions in British Columbia

Haley Piagno[1] · Reza Afshari[2]

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Abstract

Objectives Mercury occurs in the environment as a result of natural processes and human activities, including when individuals with amalgam dental fillings are cremated. This work aimed to estimate the quantity of mercury emitted to the atmosphere from crematoriums in British Columbia (BC) and assess the human health risk.

Methods A BC-specific emissions factor for mercury from crematoriums was developed and applied to an estimate of the quantity of mercury released annually to the atmosphere from crematoriums. The maximum ground-level mercury vapour concentrations resulting from crematorium emissions were estimated.

Results In BC, it is estimated that approximately 1.20 g of mercury is emitted to the atmosphere per body cremated and about 30,000 cremations were conducted in the province in 2016. It is estimated that almost 36 kg of elemental mercury was released to the atmosphere as a result. The maximum estimated peak short-term and long-term average ground-level mercury vapour concentrations associated with crematorium emissions were 0.31 $\mu g/m^3$ and 7.9×10^{-3} $\mu g/m^3$ respectively, which are far lower than the reference concentration (hazard quotient of less than 1).

Conclusion Mercury from crematoriums accounts for more than 7% of total mercury emissions to the atmosphere in BC, but risk assessment found no indication that ground-level exposures to elemental mercury vapour from crematoriums poses a significant risk to human health. If the number of cremations increases, it might reach considerable levels, highlighting the need for developing a national plan similar to other countries.

Résumé

Objectives Le mercure est présent dans l’environnement à la suite de processus naturels et d’activités humaines, notamment lors de la crémation d’individus porteurs d’amalgames. Ce travail visait à estimer la quantité de mercure rejetée dans l’atmosphère par les crématoriums en Colombie-Britannique et à évaluer le risque pour la santé humaine.

Méthodes Un facteur d’émissions spécifique à la Colombie-Britannique pour le mercure des crématoriums a été élaboré et appliqué à une estimation de la quantité de mercure rejetée chaque année dans l’atmosphère par les crématoriums. Les concentrations maximales de vapeur de mercure au niveau du sol résultant des émissions de crématorium ont été estimées.

Résultats En Colombie-Britannique, on estime qu’environ 1,20 g de mercure est émis dans l’atmosphère par corps incinéré et environ 30 000 incinérations ont eu lieu dans la province en 2016. On estime que près de 36 kg de mercure élémentaire ont ainsi été rejetés dans l’atmosphère. Les concentrations maximales moyennes estimées de vapeurs de mercure au niveau du sol associées aux émissions de crématorium étaient de 0,31 $\mu g/m^3$ et 7,9 x 10^{-3} $\mu g/m^3$, respectivement, valeurs nettement inférieures à la concentration de référence (quotient de danger inférieur à 1).

Conclusion Le mercure provenant des crématoriums représente plus de 7 % des émissions totales de mercure dans l’atmosphère en Colombie-Britannique, mais l’évaluation des risques n’a révélé aucune indication selon laquelle l’exposition au niveau du sol aux

✉ Reza Afshari
Reza.Afshari@ubc.ca

[1] School of Population and Public Health, University of British Columbia, Vancouver, BC, Canada

[2] Division of Occupational and Environmental Health, School of Population and Public Health, University of British Columbia, 2206 East Mall, Vancouver, BC V6T 1Z3, Canada

vapeurs de mercure élémentaire provenant de crématorium pose un risque important pour la santé humaine. Si le nombre de crémations augmente, il pourrait atteindre des niveaux considérables, soulignant la nécessité d'élaborer un plan national similaire à celui d'autres pays.

Keywords Mercury · Cremation · Emissions · Risk

Mots-clés Mercure · crémation · émissions · risque

Introduction

Mercury occurs in the environment as a result of natural processes (e.g., volcanic outgassing) and human activities like mining and burning of fossil fuels (Mercury n.d.). In Canada, anthropogenic mercury emissions to air are primarily attributed to coal combustion, waste incineration, and activities related to iron extraction and steel production; in 2014, an estimated 3900 kg of mercury was released to air nationally from human activities (Environment and Climate Change Canada 2016). In the environment, mercury exists in three forms—metallic (elemental) mercury, inorganic compounds, and organic compounds—and all are toxic. Exposure to mercury and its compounds is a major public health concern (World Health Organization n.d.). The extent of toxicity varies based on different forms of mercury, levels of exposure, and the routes of exposure.

Elemental mercury is also an important component of dental amalgam, comprising approximately 50% of the amalgam mixture and conferring desirable properties, including ease of manipulation and longevity (US Department of Health and Human Services 1993). Despite public concern about mercury exposure from fillings, the Canadian Dental Association cites a lack of evidence for adverse health outcomes in its support of the continued use of dental amalgam in Canada (Canadian Dental Association 2017). A related hazard that receives far less attention is that created when individuals with amalgam fillings are cremated; the temperature of cremation far exceeds the boiling point of mercury, so nearly all of the mercury present in the teeth of a cremated body is vapourized and released to the atmosphere (United Nations Environment Programme 2017).

Acute exposure to high concentrations of elemental mercury vapour, such as workers who were exposed to 0.79 mg/m^3 for 1.5 years, 0.9 mg/m^3 for over 5 years, and 0.014–0.076 mg/m^3 for over 15 years, or in cases that are exposed for a longer period such as in occupational settings, may be followed by chest pains, dyspnea, coughing, hemoptysis, and sometimes interstitial pneumonitis leading to death (Friberg 1991; Asano et al. 2000; Fields et al. 2017; Lien et al. 1983).

Once mercury is released, it may undergo further conversion by microorganisms to methylmercury, generally regarded as the most toxic form of mercury. Methylmercury bioaccumulates and biomagnifies in the food chain, reaching its highest concentrations in long-lived predatory species.

In fish and other animals, methylmercury is associated with adverse behavioural, neurochemical, hormonal, and reproductive effects. Consumption of fish is the primary route by which humans are exposed to methylmercury, and exposure produces similar adverse biological effects. Of particular concern are the effects of methylmercury on neurological development (Friberg 1991; Antunes Dos Santos et al. 2016; Hong et al. 2012).

Mercury release from crematoriums is generally unregulated in North America. Regulatory Framework for Air Emissions, Canada, does not specifically discuss highly toxic mercury as an air pollutant from crematoriums (Regulatory Framework for Air Emissions 2007). Mercury release from crematoriums is also not subject to licensing and regulatory frameworks provided in Cremation, Interment and Funeral Services Act and Regulation (Cremation, Interment and Funeral Services Act 2004; Cremation, Interment and Funeral Services Act 2016) and funeral association policies and regulations in British Columbia (British Columbia Funeral Association n.d.).

The concentration of mercury in cremation exhaust is rarely measured in North America; instead, emissions factors are typically employed to estimate the quantity of mercury emitted during cremation. A factor commonly used is that developed by the United States Environmental Protection Agency (EPA): 3.29×10^{-3} lb (1.49 g) per each body cremated, based on emissions testing conducted at a single propane-fired incinerator in 1992 (US Environmental Protection Agency 2017). The representativeness of this factor, however, is limited due to spatial and temporal variations in dental amalgam use; the amount of mercury per person varies considerably with the number and mass of amalgam fillings. Some have thus used oral health data specific to the region of interest in order to estimate the amount of mercury present in cremated bodies. In Minnesota, for example, researchers reviewed the dental records of 1000 subjects between the ages of 63 and 79 and estimated a mean mass of mercury per person of 2.3 g (Myers 2015). In the absence of source-specific data, the United Nations Environment Programme recommends the use of default "low-end" and "high-end" emissions factors of 1 g and 4 g, respectively, per body cremated, based on a review of data from North America and Europe (United Nations Environment Programme 2017).

Air pollutant emission inventory report by Environment and Climate Change Canada estimated that total air pollutant emission of mercury could reach 280 kg (Air Pollutant Emission Inventory Report 1990). In BC, using the US EPA emissions factor, Environment and Climate Change Canada estimates that 42.9 kg of mercury was emitted to the atmosphere from crematoriums in 2015. Given the above, it is reasonable to expect that mercury emissions from crematoriums in the province may actually be substantially higher.

Crematoriums are sources of air pollution including mercury emission and may cause plausibly subtle chronic health effects due to long-term low-dose exposure. Characterizing the nature and strength of the evidence of causation and dose-response assessment are needed from a health perspective.

Objectives of this work were to first estimate the quantity of mercury released to the atmosphere from crematoriums in BC using national oral health data and province-specific rates of mortality and cremation, and then to assess the human health risk associated with exposure to elemental mercury vapour at ground level in the vicinity of a BC crematorium. Our goal was to raise a flag and to inform decision-making around environmental permitting and pollution prevention efforts at the regional and provincial levels and address public concerns with respect to human health and environmental impacts of crematoriums.

Methods

Estimate of mercury emissions

The quantity of mercury emitted to the atmosphere annually from crematoriums in BC was estimated based on the number of cremations conducted each year in the province and the estimated mass of mercury released per body cremated.

The number of cremations conducted in British Columbia in 2016 was estimated based on the province's age-stratified population and mortality rates and a cremation rate of 82% (Cremation Association of North America 2016). For each age category, the number of bodies cremated in 2016 was estimated using the following equation:

$$\text{bodies/year} = \text{population} \times \text{mortality rate} \times 82\%$$

A Canada-specific emissions factor for mercury release from crematoriums was derived from oral health data (specifically, the mean number of amalgam-filled tooth surfaces per person, by age) collected in cycle 1 of the Canadian Health Measures Survey (Richardson 2014) and an estimate of the mean mass of amalgam per filled surface of 0.26 g from Adegbembo et al. (Adegbembo et al. 2004). It was assumed that mercury makes up 50% of the mass of each amalgam filling. The emissions factor is the death-weighted average of the age-specific estimates of the mass of mercury per person, each calculated according to the following equation:

$$\text{mass}_{\text{Hg}}/\text{body} = \#\text{amalgam tooth surfaces} \times 0.26\ \text{g/surface} \times 50\%$$

It is assumed that the mass of mercury contained in body tissues is negligible relative to the mass contained in dental fillings and that all mercury contained in dental fillings is vapourized and released to the atmosphere (United Nations Environment Programme 2017). Table 1 summarizes the input data and derivation of the Canada-specific emissions factor for mercury release from crematoriums.

Table 1 Summary of the input data and derivation of the Canada-specific emissions factor for mercury release from crematoriums

Age category	Mean no. amalgam-filled surfaces per person (Richardson 2014)	Mean mass of amalgam per filled surface (g) (Adegbembo et al. 2004)*	Mass of mercury per filled surface (g) (calculated)	Mass of mercury per person (g) (calculated)
< 1	0	0.26	0.00	0.00
1–4	1	0.26	0.26	0.13
5–9	1.97	0.26	0.51	0.26
10–14	1.43	0.26	0.37	0.19
15–19	1.43	0.26	0.37	0.19
20–24	8.01	0.26	2.08	1.04
25–29	8.01	0.26	2.08	1.04
30–34	8.01	0.26	2.08	1.04
35–39	8.01	0.26	2.08	1.04
40–44	8.01	0.26	2.08	1.04
45–49	8.01	0.26	2.08	1.04
50–54	8.01	0.26	2.08	1.04
55–59	8.01	0.26	2.08	1.04
60–64	8.01	0.26	2.08	1.04
65–69	9.58	0.26	2.49	1.25
70–74	9.58	0.26	2.49	1.25
75–79	9.58	0.26	2.49	1.25
80–84	9.58	0.26	2.49	1.25
85–89	9.58	0.26	2.49	1.25
90+	9.58	0.26	2.49	1.25
Total	–	–	–	1.20**

*Given that primary teeth are substantially smaller than permanent teeth, the mean mass of amalgam per filled surface is likely lower among children. Given the small number of deaths (and cremations) among children relative to adults, this difference is negligible

**BC-specific emissions factor (death-weighted average mass of mercury per person, i.e., average mass of mercury in cremated bodies)

Human health risk assessment

A quantitative assessment of human health risks associated with exposure to mercury vapour emitted from crematoriums in BC was undertaken according to the standard paradigm established by the US National Research Council (NRC) (National Research Council 1983) and endorsed by both the US EPA and Health Canada: problem formulation, hazard identification, dose-response assessment, exposure assessment, and risk characterization. Given the limited public availability of detailed specifications for crematoriums in the province, the analysis was conducted for a generic facility with cremation gas properties and stack specifications typical of the industry, based on a cursory review of publically available permits and approvals for facilities located outside BC.

Problem formulation Part A of the analysis assessed the risk to human health associated with chronic inhalation exposure to mercury vapour at the maximum estimated long-term average 24-h period ground-level concentration resulting from crematorium emissions. In part B, we evaluated the maximum estimated short-term average ground-level mercury vapour concentrations against short-term exposure limits. In both cases, risk was assessed at the individual receptor level, with the receptor positioned at ground level and continuously exposed.

Hazard characterization In humans, chronic inhalation exposure to elemental mercury vapour at subacute concentrations may adversely affect the central nervous system resulting in, for example, increased excitability, irritability, excessive shyness, and tremors (Mercury n.d.). Chronic, subacute exposure to mercury vapour may also induce psychotic reactions (Friberg 1991). In exposed workers, a range of clinical effects are reported at a concentration of 0.79 mg/m^3 (for over 1.5 years), 0.9 mg/m^3 (for over 5 years), and 0.014–0.076 mg/m^3 (for over 15 years). Elemental mercury is not currently classified as a human carcinogen due to inadequate evidence of carcinogenicity, so this assessment exclusively focuses on non-cancer endpoints (International Agency for Research on Cancer (IARC) 2017).

Dose-response assessment The US EPA defines a reference concentration (lifetime exposure limit) of 0.3 μg/m^3 for inhalation exposure to elemental mercury vapour (Integrated Risk Information System (IRIS) 1988); in Canada, a more conservative reference concentration of 0.06 μg/m^3 has been suggested (Richardson et al. 2009). Both values were considered in the assessment of risks associated with long-term exposure to ground-level mercury vapour from crematoriums.

The exposure concentration believed to be immediately dangerous to life or health is 10,000 μg/m^3 (National Institute for Occupational Safety and Health 1994). In British Columbia, the short-term (8-h time-weighted average) occupational exposure limit for elemental mercury vapour is 25 μg/m^3 (WorksafeBC 2012). This occupational limit is determined for the protection of healthy adult workers in industrial settings that have a shift of 8 h per day for 5 days per week and about 50 weeks per year. To adjust for general population that comprises sensitive subpopulations such as children, pregnant women, and elderly, we *separately* applied 10 times uncertainty factor and 8-/24-h adjustment factor respectively to draw a practical value for comparison (i.e., 0.75 mg/m^3).

Exposure assessment We used the EPA's Screening Procedures for Estimating the Air Quality Impact of Stationary Sources (revised 1992) to determine the maximum estimated ground-level mercury vapour concentrations resulting from crematorium emissions. The initial application of simple screening is recommended to determine if the potential for adverse outcomes exists; more detailed analysis is warranted only if results suggest that a significant threat to air quality exists. The simple screening calculations incorporate a high degree of conservatism to allow reasonable certainty that maximum concentrations will not be underestimated (US Environmental Protection Agency 1992). In our model, ambient wind speed and temperature, cremation gas properties, stack specifications, and mercury emission rate were included; however, for simplicity, building downwash and the effects of plume impaction on elevated terrain were excluded.

Inputs to the screening model included:

- *Ambient wind speed and temperature.* Weather data for Vancouver were applied to the generic facility. Hourly wind speed and temperature data collected in 2016 at the Vancouver International Airport were retrieved from the Government of Canada's online repository of historical climate data at http://climate.weather.gc.ca.
- *Cremation gas properties.* According to the Cremation Association of North America (CANA), the exhaust rate during cremation typically ranges from 0.94 to 1.18 m^3/s and cremation chambers generally operate between 750 °C and 1150 °C (Que 2001). The temperature of exhaust upon release to the atmosphere is substantially lower, however, owing to energy losses between the cremation chamber and the point of exit from the stack; based on a review of publically available cremation facility permits and approvals, the temperature of cremation gas at the point of exit from the stack is typically in the range of 450–600 °C.
- *Crematorium stack specifications.* Stack height and diameter are properties unique to each facility. In this assessment, the stack height was assigned a value of 7 m (assuming a building height of 6 m and a stack rise of 1 m above the building roof height); the stack internal diameter was assigned a value of 0.6 m (Montana Air Quality 2013; Department of Natural Resources 2011).

- *Mercury emission rate.* The Canada-specific emissions factor and a conservative cremation duration of 1 h were used to estimate the rate of mercury emission from the crematorium stack for the long-term exposure scenario. Typically, cremation duration ranges from 1 to 3 h and depends on body mass, body fat percentage, operating temperature of the cremation chamber, and the type of cremation container in which the body is placed (Cremation Resource n.d.). For the short-term exposure scenario, a peak emissions factor of 8.32 g per body cremated was used in place of the Canada-specific emissions factor, based on the maximum number of amalgam surfaces counted in any individual in the Canadian Health Measures Survey (Richardson 2014).

In conducting an exposure assessment as described, important considerations include building downwash and the effects of plume impaction on elevated terrain. Both may result in higher contaminant concentrations at ground level than would otherwise occur. For simplicity, neither building downwash nor elevated terrain was assumed to influence plume dynamics for the generic crematorium.

Table 2 Estimated number of cremations in 2016 in British Columbia

Age category	Population (2016) (Statistics Canada 2016)	Mortality rate (per 1000 pop) (Statistics Canada 2009)	Deaths (2016) (calculated)	Cremations (2016) (calculated)
< 1	44,125	3.7	163	134
1–4	176,500	0.2	35	29
5–9	236,900	0.1	24	19
10–14	233,860	0.1	23	19
15–19	258,980	0.3	78	64
20–24	287,560	0.6	173	141
25–29	303,000	0.6	182	149
30–34	313,750	0.7	220	180
35–39	293,590	0.8	235	193
40–44	295,045	1.2	354	290
45–49	322,365	1.8	580	476
50–54	354,375	2.9	1028	843
55–59	354,925	4.7	1668	1368
60–64	324,095	7.1	2301	1887
65–69	287,520	10.7	3076	2523
70–74	201,785	16.0	3229	2647
75–79	145,225	27.8	4037	3311
80–84	105,255	49.3	5189	4255
85–89	67,510	86.0	5806	4761
90+	41,685	191.9	7999	6559
Total	4,648,050	–	36,400	29,848

Risk characterization For non-cancer endpoints, risk is expressed in terms of the hazard quotient (HQ), which relates the exposure concentration to reference concentration. This quantitative estimate of risk is compared with a measure of "acceptable" risk to determine requirements for risk management (if any). For non-cancer endpoints, British Columbia defines acceptable risks as any described by HQ less than 1.0 (Health Canada 2010). In this analysis, the HQ was calculated for both long- and short-term exposure scenarios to evaluate the risks to human health from exposure to mercury vapour associated with crematorium emissions.

Results

Estimate of mercury emissions

We estimated that in 2016, almost 30,000 cremations were conducted in BC (Table 2). From Table 1, the death-weighted average mass of mercury contained in the amalgam fillings of deceased individuals in Canada is 1.20 g; assuming that the mass of mercury contained in body tissues is negligible relative to the mass contained in dental fillings and that all mercury contained in dental fillings is vaporized and released to the atmosphere, the Canada-specific emissions factor for mercury from crematoriums is 1.20 g per body cremated. The estimated quantity of mercury emitted annually from crematoriums in BC is thus 29,848 bodies cremated × 1.20 g per

Table 3 Summary of the input to the simple screening model (data are typical values amassed from several sources and used to represent a generic cremation facility in British Columbia)

Variable	Value
Long-term exposure scenario	
Ambient temperature	11.23 °C
Wind speed	3.97 m/s
Stack inside diameter	0.6 m
Stack height	7 m
Gas flow rate	1.2 m^3/s
Gas exit temperature	500 °C
Cremation duration	1 h
Mass Hg per body	1.20 g
Averaging time	Annual
Short-term exposure scenario	
Ambient temperature	24.69 °C
Wind speed	13.68 m/s
Stack inside diameter	0.6 m
Stack height	7 m
Gas flow rate	1.2 m^3/s
Gas exit temperature	500 °C
Cremation duration	1 h
Mass Hg per body	8.32 g
Averaging time	8 h

body cremated = 35,818 g (35.8 kg). This result suggests that crematorium releases account for more than 7% of overall emissions of mercury to the atmosphere in BC (roughly estimated to be close to 500 kg in 2015) (Environment and Climate Change Canada 2016).

Human health risk assessment

Input to the simple screening model is summarized in Table 3. These data are typical values amassed from several sources and used to represent a generic cremation facility in British Columbia.

Part A—long-term exposure

The mean temperature and wind speed measured at the Vancouver Airport in 2016 were 11.2 °C and 4.0 m/s, respectively. Under these "normal" conditions and using other inputs as described in the Methods section and summarized in Table 3, the maximum estimated annual average ground-level elemental mercury vapour concentration associated with crematorium emissions was 7.9×10^{-3} μg/m^3. At this level of exposure, assuming a reference concentration of 0.3 μg/m^3, the hazard quotient is 0.026. If a more conservative reference concentration of 0.06 μg/m^3 is used, the hazard quotient increases to 0.13. In either case, the hazard quotient is sufficiently less than 1 and the risk is deemed acceptable; i.e., there is no significant risk of adverse effects on human health from long-term exposure to mercury vapour at a concentration of 7.9×10^{-3} μg/m^3.

Part B—short-term exposure

The maximum 8-h average temperature and wind speed measured at the Vancouver Airport in 2016 were 24.7 °C and 13.7 m/s, respectively. Under these conditions and using other inputs as described in the Methods section and summarized in Table 3, the maximum estimated 8-h average ground-level elemental mercury vapour concentration associated with crematorium emissions was 0.31 μg/m^3. This level of exposure is 1.2% of the 8-h time-weighted average *occupational* exposure limit of 25 μg/m^3. This value is also less than half of our arbitrary estimated reference value of 0.75 mg/m^3, in which *occupational* exposure limit was adjusted for different durations of exposure in the general public and the inclusion of sensitive subpopulations.

As in the case of long-term exposure, there is no indication that short-term exposure to peak ground-level mercury vapour concentrations associated with crematorium emissions poses a significant risk to human health.

Discussion

Our results suggest that ground-level exposure to elemental mercury vapour emitted from crematoriums in BC does not pose a significant risk to human health at the individual receptor level. This is contrary to public perception, but agrees with the findings of similar analyses described in the literature, for example in Green et al. from the USA (Green et al. 2014).

We have also estimated that mercury emitted from crematoriums in BC represents more than 7% of total mercury emissions to the atmosphere in the province. Despite the low contribution of mercury emissions from the crematoriums, these could be important as, unlike industry, crematoriums are located in the vicinity of the cities, in which high-risk populations may be in close contact. Details are likely to vary among actual cremation facilities in the province; the analysis should be repeated on a site-specific basis where a specific concern exists and facility details are available.

The indirect contribution of mercury release from crematoriums through bioaccumulation and biomagnification in the food chain is difficult to quantify, but may be of greater concern than those effects (or lack thereof) resulting from direct exposure to elemental mercury vapour. Elemental mercury in the atmosphere has a residence time of up to 3 years and may travel thousands of kilometres before it is converted to soluble, reactive forms and deposited to soil and water (National Atmospheric Deposition Program 2007). Once there, mercury may undergo further conversion by microorganisms to methylmercury and bioaccumulate and biomagnify in the food chain. Consumption of fish is the primary route by which humans are exposed to methylmercury that may cause neurological development problems (Friberg 1991).

In recognition of these impacts, the United Nations Environmental Programme (UNEP) penned the Minamata Convention on Mercury with the aim to manage risks to human health and the environment by reducing releases of mercury and its compounds to the environment (United Nations Environment Programme (UNEP) 2013). The Convention has been ratified by 69 countries, including Canada.

Some nations have already taken steps to reduce mercury emissions from crematoriums. Most notably, the United Kingdom has established CAMEO, the Crematoria Abatement of Mercury Emissions Organisation, to facilitate fulfillment of a national objective to implement mercury abatement at no less than 50% of crematoriums in the nation (UK Department for Food Environment and Rural Affairs 2005).

In BC and Canada, mercury emissions from crematoriums are unregulated. Results from the present study support the establishment of regulatory requirements for the reduction of mercury emissions from crematoriums in the province for the protection of human health and the environment. Mercury reduction may be accomplished by implementation of emission controls or by removal of dental amalgam from the mouths of deceased individuals before cremation.

The Canada-specific emissions factor is in reasonable agreement with the US EPA emissions factor of 1.49 g per body cremated and is within the range of default emissions factors recommended by the United Nations Environment Programme. However, the Canada-specific emissions factor should be refined through analysis of the oral health records of a representative sample of the BC population and/or emissions testing at crematoriums throughout the province.

We estimated that nearly 36 kg of elemental mercury is introduced in the environment yearly from cremation activities. The real margin of exposure for people living around crematoriums would be lower taking both emitted mercury and background mercury exposures together. Also, the margin of safety that is the difference between the margin of exposure and acceptable limits would be narrower as the duration of exposure for the general public (i.e., 24 h) is longer than for occupational settings and includes sensitive subpopulations.

Limitations

Partitioning of the mercury contained in dental amalgam may also vary, depending on conditions. This analysis assumed that 100% of mercury contained in amalgam fillings is released as vapour during cremation and that 100% of the mercury vapour released is emitted to the atmosphere. Generally, at facilities where no emission controls are in place, this is a close approximation of reality, although a small proportion of mercury released from a cremated body may adhere to surfaces in the cremation chamber or be bound to the ash remaining after cremation is complete (United Nations Environment Program 2017). Ideally, the BC-specific emissions factor for mercury from crematoriums would be based on the results of systematic emissions testing at crematoriums throughout the province.

In the absence of emissions testing data, a BC-specific emissions factor was developed based on oral health and mortality data. The factor derived herein may underestimate mercury emissions from crematoriums in the province. The factor considers the contribution of amalgam fillings only and neglects that of amalgam used in other types of restorations for which quantitative data was unavailable. The amount of amalgam used under crowns and bridges, for example, may be substantial; Myers reports that the mass of amalgam under a molar crown may be as high as 2.20 g (Myers 2015). Furthermore, the broad age classifications associated with the oral health data used in the development of the BC-specific emissions factor means that the factor does not completely account for the concomitant increase in number of fillings and deaths with age. For example, the mean number of amalgam-filled surfaces among Canadians aged 20–64 was reported to be 8.01; it is likely, however, that the number of amalgam fillings actually increases with age, with those aged 20 having fewer than 8.01 fillings and those aged 64 having more than 8.01 fillings, on average. The risk of death also increases with age, such that more people aged 64 die each year than people aged 20. As previously noted, the BC-specific emissions factor should be refined through analysis of the oral health records of a representative sample of the BC population.

A human health risk assessment for exposure to elemental mercury vapour from crematoriums was conducted for a generic facility in the province of BC. Caution is advised in generalizing the findings presented herein; although the results suggest (with a high degree of conservatism) that ground-level mercury vapour concentrations associated with crematorium emissions pose no risk to human health, the analysis should be repeated on a site-specific basis where a specific concern exists and facility details are available.

Finally, our analysis did not consider other sources of exposure to elemental mercury nor exposure to other chemicals with similar health effects and mechanisms of action. Depending on proximity to other mercury emission sources, mercury vapour may be present in ambient air at the point of impingement of the crematorium plume, contributing to exposure concentrations in excess of that estimated in this analysis. Individuals may also be exposed to elemental mercury through dermal contact with mercury present in soil, or through ingestion of contaminated food or water, for example. The effects of multiple sources and routes of exposure should be considered in an assessment of individual risk associated with exposure to elemental mercury.

This study assumes that mercury contained in a body is entirely vapourized and emitted into the atmosphere upon cremation, which is probably an “overestimation.” The contribution of the fuel, cardboards (cascades), and cloths that are used by the crematoriums in overall mercury emissions was not evaluated.

This study is subject to a set of assumptions and estimations related to parameters that was applied to assess health risk. In addition, we did not evaluate the building downwash and the effects of plume impaction on elevated terrain.

Conclusion

This study underlines that the main concern about mercury from crematoriums is not acute exposure to immediately dangerous ground-level concentrations but long-term indirect exposure from the contamination of the environment and the food chain, although more difficult to assess quantitatively. It is important to inform decision-making around environmental permitting and pollution prevention to motivate further regulation. Crematoriums are a source of air pollution as a result of combustion of caskets and human bodies, as well as companion clothing, and should be subject to the regulatory framework covering all sources of air pollutants, notably including mercury. Environmental monitoring of mercury emission from crematoriums is warranted. This would constitute a significant contribution to this field, as current information appears to rely on environmental modeling rather than on monitoring. In addition, crematorium installations should implement processes such as filters to reduce their atmospheric emissions to limit mercury emission. Feasibility of removing dental amalgam fillings prior to cremation should also be investigated. The increasing rate of cremations is likely to continue, highlighting the need for selecting a zone for installing crematoriums. The frequency of daily cremations should also be regulated taking into account public health concern with regard to highly emitted toxic mercury. Ideally, we would like to move toward prioritizing crematoria emissions in the work plan of the regulatory development team, Air Quality & Climate Change, Metrovancouver (Jennejohn 2018) and seek an update with relevant information in the Cremation, Interment and Funeral Services Act and the policies and regulations of the BC Funeral Association.

Finally, our study infers that environmental pollution is the primary source of exposure, and therefore further enforcing and developing public health interventions at the population level is warranted.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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