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FIELD INQUIRY: CREMATORIA EMISSIONS AND AIR QUALITY IMPACTS

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PRIMARY INQUIRY

A municipality received an application from a funeral home to install a cremator within their facility. Objections were received from nearby residents who were concerned about potential exposure to harmful emissions. A public health unit was contacted to help answer the following questions:

1. Do crematoria emit harmful pollutants?
2. Is there evidence of health impacts due to exposure to crematoria emissions?
3. What is standard practice for siting of crematorium in proximity to residential areas?
4. What steps can be taken to minimize crematoria emissions to reduce exposure risks?

BACKGROUND

In Canada, preference for cremation over burial has been increasing since the 1950s. The Cremation Association of North America (CANA) estimated that in 2016 approximately 70% of human remains in Canada were cremated, and this may rise to about 80% in 2020.[1,2] The increased demand for cremation services can only be met by constructing new crematoria or expanding existing facilities. Both can be expected to lead to a rise in inquiries about potential health risks to nearby communities. This field inquiry therefore focusses on crematoria-related air pollution and human health risks.

METHODS

A rapid literature search was undertaken for articles related to health and air quality issues and their association with combustion processes in crematoria. Articles were identified using EBSCOhost (Biomedical Reference Collection: Comprehensive, CINAHL Complete, GreenFILE, MEDLINE with Full Text, Urban Studies Abstract) and Google Scholar. Terms used in the search included variants and Boolean operator combinations of (cremat* OR "funeral home") AND (health OR illness OR irrita* OR annoy* OR emission OR "air quality"). Inclusion criteria were publication date (no date restriction), English language, and human subjects. Google was used to access relevant public agency websites and grey literature including Canadian public health documents concerning cremation facilities and examples of current practices elsewhere. Citation chaining was used to further expand the resource lists.

1. Do crematoria emit harmful pollutants of public health concern?

Types of emissions

Cremation is a combustion process whereby a casket and human remains (or animal remains in pet crematoria) are incinerated at a high temperature in a closed chamber. Cremation in Canada is normally fuelled by gas and will produce emissions associated with fossil fuel combustion as well as emissions related to the material being combusted.[3,4] This can include:

- **Combustion gases:** carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO_2) and volatile organic compounds (VOC);
- **Particulate matter and fine dust:** PM_{10} and $PM_{2.5}$;
- **Organic pollutants:** Compounds resulting from incomplete combustion processes or formed when organic compounds react with chlorine in materials such as plastics. These pollutants can include polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (PCDFs) and polycyclic aromatic hydrocarbons (PAH) amongst others;
- **Heavy metals:** Mercury (Hg) arising from volatilization of Hg in dental amalgam in fillings and a small quantity of various metals in tissues of the individual, or personal memorial items included in the casket.

The pollutants of most concern are those known to be toxic to humans and which can bioaccumulate in tissues (e.g., PCDD/Fs and Hg) as well as fine particulate matter ($PM_{2.5}$), which can negatively impact the heart and lungs and is associated with some chronic illnesses and adverse birth outcomes.[2,3,5-7] Evidence on the release of radioactive particles, following cremation of deceased patients who had been treated with radioactive substances (e.g., cancer treatments) has not been widely studied but has been raised as an emerging area of public interest and concern.[8-10]

Level of emissions

Crematoria are usually considered small-scale installations with relatively low total emissions compared to other types of incineration facilities such as municipal waste incinerators or industrial processes. Crematoria contribute approximately 5% of total PCDD/Fs, 6% of total Hg emissions and 0.25% of $PM_{2.5}$ emissions in Canada.[3,11] These estimates are based on the number of cremations reported per year and pollutant-specific emissions factors for crematoria.[12,13] Most large-scale facilities generating high levels of emissions will report to the National Pollutant Release Inventory (NPRI) for Canada. For the most recent year of reporting (2017), no human crematoria and only one pet crematorium reported to the NPRI. This particular facility processes a very large throughput of animal remains that is atypical of the volume processed at most human or pet crematoria.

The relative contribution of an individual crematorium to local air pollution will depend on the other potential sources of pollutants in the vicinity, the number of cremations and composition of the remains, the design of the system, the operation of the cremator, and emissions control measures, as described in Table 1.[14] Table 2 summarizes the literature reporting measured ambient concentration (MA), predicted exposure (PE), or measured flue gas (MF) concentration of PCDD/Fs, Hg or $PM_{2.5}$. Most studies report measured concentrations of pollutants in flue gas only. Few studies of crematoria emissions have measured ambient concentrations of air pollutants or modelled the predicted exposures.

TABLE 1. FACTORS AFFECTING THE LEVEL OF POSSIBLE EMISSIONS FROM CREMATORIA

The composition of the casket and remains	• The size of the corpse can affect the initial combustion temperature, the duration over which emissions are released (1.5 to 5 hours), and the total quantity of emissions.[13] • Hg emissions are affected by the presence of dental amalgam fillings containing Hg.[2] Up to 0.5 g of Hg is present per filling, some of which may be volatilized and emitted into the atmosphere.[3,15] • Plastics or polystyrene parts in the funeral casket or personal/memorial items included in the casket can increase the potential for fine particulates and organic pollutants (e.g., PAHs and PCDD/Fs) to form within the combustion chamber.[3] • Burial caskets coated in insecticides or preservatives can be a source of PCDD/Fs. Caskets made from untreated wood, cardboard, and similar materials release fewer harmful substances.[16,17] • The presence of radioactive substances within the remains, either from devices or as a result of radiotherapy, could result in low levels of radiation or radioactive particles to be present in the combustion chamber.[8,18]
The design of the system	• The presence of two combustion chambers in a cremator allows for high-temperature treatment of gases and particulates, which reduces released odours, fine dust, and products of incomplete combustion (PICs) such as PCDD/Fs. • Chimney height can affect the distribution and dilution of emissions into the atmosphere and dispersion at ground level.[4,19] • Older equipment is less likely to be fitted with modern process controls and monitors and may be more prone to failure.[20,21]
Operational parameters of the cremator	• Low start-up temperatures can cause incomplete combustion in the initial stages of cremation, resulting in release of particulates or PICs such as PCDD/Fs.[20] • High temperature (e.g., >850°C) and residence time (2 s) for gases in the second chamber can reduce the quantity of PICs released, as can ensuring sufficient O_2 for combustion (e.g., 6%).[3,20] • Modern equipment with process controls and continuous monitoring of pollutants can alert operators of operational problems. High carbon monoxide (CO) levels can indicate inefficient combustion and potential formation of PICs. • Absence of monitoring can lead to failure to detect operator error or equipment failure, resulting in possible unintentional release of pollutants.
Emissions control measures	• Flue gas treatment, acid neutralization, activated carbon adsorption, dust collection, and good operation and maintenance practices can reduce emissions of key pollutants.[4,14] • Measures that control the release of dust can reduce emissions of fine particulates and PCDD/Fs.[16,19,20,22] • Hg-abatement equipment, such as activated carbon filters, scrubbers, and technologies that bind or precipitate Hg, are effective at reducing Hg emissions.[23,24] • Removal of Hg at source by the removal of dental amalgams prior to cremation can be both cost and environmentally effective; however, it is less socially acceptable, and difficult to impose.[25]

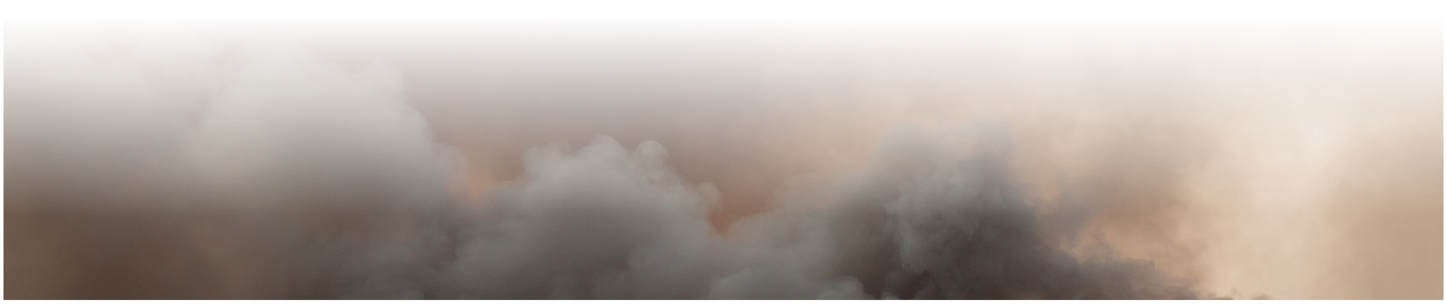


TABLE 2. EMISSIONS LEVELS FROM CREMATORIA POLLUTANT STUDIES

Study Location	Study Type	PCDD/Fs (ng TEQ/m³)	Hg (µg/m³)	$PM_{2.5}$ (mg/m³)
Taiwan[26]	MA	0.0005 (downwind of crematoria with no dust control)	n/a	n/a
New Zealand[27]	MA	n/a	110-120 µg/kg (downwind mean soil concentration)	n/a
Virginia, USA[28]	PE	0.0000008 (max exposure) 0.0000005 (nearest school)	0.003 (max exposure) 0.002 (nearest school)	n/a
Taiwan[26]	MF	0.32 (bag filter) 2.36 (no dust control)	n/a	n/a
Taiwan[29]	MF	0.14 (single crematorium)	n/a	n/a
Mexico [14]	MF	n/a	n/a	11-35 (120 min cremation) 25-205 (70 min cremation) No dust control at either crematoria
Denmark[30]	MF	0.2–0.7 (2 crematoria)	n/a	n/a
Italy [31]	MF	1.13, 1.10 (1 crematoria, 2 cremations)	2.8, 293, 76 (1 crematoria, 3 cremations)	2.2, 1.1, 1.9 (1 crematoria, 3 cremations)*
Japan[22]	MF	0.00005-11 (various levels of emissions control)	n/a	n/a
Japan[32]	MF	n/a	0.2-30.3 (average 3.6) (7 crematoria)	n/a
Example ambient air quality standards		< 0.1 (UNEP[33])	2 (24-hour average) (Ontario AAQC[34])	0.027 (24-hour average) (CAAQ[35])
Reference exposure limits for acute (A), 8-hour (8) and chronic (C) exposure by inhalation[36]		0.04 (C)	0.6 (A) 0.06 (8) 0.03 (C) (Hg, and inorganic Hg compounds)	

MA: measured ambient concentration; PE: predicted exposure concentration; MF: measured flue gas concentration; ng = nanograms; µg = micrograms; TEQ = toxic equivalency; n/a = not assessed
*total particulate matter

There is substantial variation in MF concentrations among the studies, illustrating how design, operation, and emissions control measures can significantly impact the levels of emissions released. Only one study measuring downwind ambient air concentrations of PCDD/Fs was identified but no studies measuring Hg or $PM_{2.5}$. One study reported downwind soil concentrations of Hg, which was detected up to 30 m away from crematoria sites. Other studies in Sweden[37] and Norway[38] have detected Hg in soils downwind of anthropogenic sources including crematoria, although the relative contribution and correlation with ambient air concentrations have not been reported.

Determining relative contribution of crematoria emissions to local air quality can be difficult. Some countries have set specific national pollution control regulations for emissions of Hg and other air pollutants from crematoria, but Canada has no such regulatory limits at a federal level.[23,39] Canadian Ambient Air Quality Standards (CAAQS)[35] exist for $PM_{2.5}$ but not for PCDD/Fs or Hg. Some provinces may use Ambient Air Quality Criteria (e.g., Ontario[34]) or similar standards for these substances; however, attributing ambient exceedances to a single source can be difficult. Computational air dispersion modelling using local air conditions, geography, and emission factors can be used to predict exposure levels from a point source of pollution. This approach was used to estimate exposures concentrations from a crematoria in Virginia, USA, (Table 2) and found that PE was well below reference exposure limits for PCDD/Fs and Hg.[12,28] Reports to local authorities for proposed crematoria also use this approach but may estimate emissions using manufacturers' reported emissions factors. Most reports found on public body websites using this approach identified minimal or no impact on sensitive receptors, but potentially harmful pollutants such as PCDD/Fs, Hg or $PM_{2.5}$ were not always reported.[28,40,41]

There are few studies that have assessed the release of radioactive particles from crematoria. In West Australia, an atmospheric dispersion study modelled Iodine-131 (I^{131}) emissions following the cremation of a deceased cancer patient who had received a high dose of I^{131} shortly before death. The study estimated that environmental limits for atmospheric emissions of I^{131} could have been exceeded at distances of 440 m and 1610 m downwind of the chimney, but ambient I^{131} levels were not measured.[10] Events such as this are unlikely to represent routine conditions, and following the Canadian Nuclear Safety Commission's Radiation Protection Guidelines for the Safe Handling of Decedents, should minimize radiation exposure for crematoria and other death care operators, as well as the release of radioactive particles into the environment.[18]

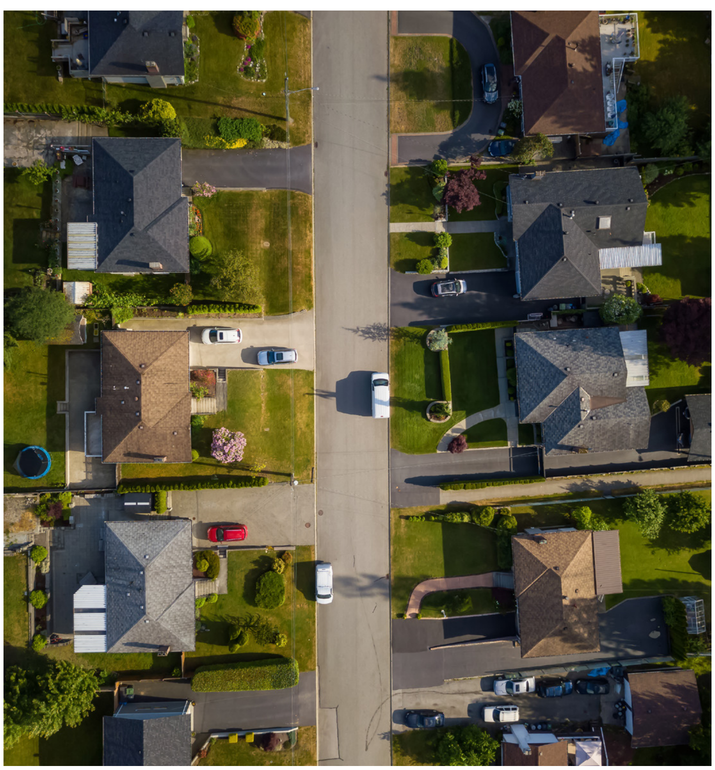
2. Is there evidence of health impacts due to exposure to crematoria emissions?

As mentioned in Section 1, the pollutants of most concern from crematoria emissions are PCDD/Fs, Hg and fine particulate matter ($PM_{2.5}$).[2,3,5-7] PCDD/Fs and Hg are known to be toxic to humans and can bioaccumulate in tissues. PCDD/Fs are classified as possible human carcinogens and Hg is a neurotoxin. Exposure to $PM_{2.5}$, which can reach deep into the lungs, can increase the risks of heart disease, lung cancer, asthma, and adverse birth outcomes, and exacerbate other conditions such as diabetes. For these key pollutants, agencies such as the World Health Organization (WHO) and the United States Environmental Protection Agency (USEPA) advise that care should be taken to limit exposure, particularly for vulnerable populations such as babies, children, pregnant women, and the elderly.

The level of exposure to these pollutants caused by crematoria has not been widely studied. A review of the literature found only one study that investigated health outcomes amongst residents living in proximity to crematoria. The study assessed the risk of stillbirth, neonatal death, and lethal congenital anomalies among babies of mothers living close to incinerators or crematoria in Cumbria, England, between 1956 and 1993.[42] An increased risk of stillbirth and anencephalus was found to be associated with residential proximity to crematoria; however, a causal effect could not be inferred. In this study, the distance between a residential postcode and a crematorium was used as a surrogate for exposure. Some of the crematoria were located near industrial sites where other pollution sources may have been present, but neither emissions levels from crematoria nor ambient concentrations of pollutants at receptor properties were measured.

The health impacts of living in proximity to waste incineration facilities have been more widely studied than crematoria. Waste incinerators tend to be much larger-scale installations, and also have more varied inputs than crematoria, but these facilities also produce combustion emissions including trace metals, particulates, and organic compounds such as PCDD/Fs. A review of the literature from 2012 on the health impacts of thermal treatment of municipal solid waste (MSW) around the world found that living in close proximity to older MSW incinerators with high dioxin emissions (e.g., 16-80 ng/m^3 TEQ) was associated with adverse health outcomes including congenital anomalies and non-Hodgkin's lymphoma.[43] These levels exceed all those recorded for crematoria (Table 2) as well as permitted dioxin emissions levels in Canada and Europe (0.05-0.50 ng/m^3 TEQ). These incinerators also represent much larger point sources of pollutants compared to crematoria, processing in excess of 100 times the quantity of material per day.

Other studies assessing health effects of crematoria emissions have considered occupational exposures to Hg, dust or radiation.[9,44,45] The occupational exposure studies identified do not link exposures to any adverse health outcomes. Exposure to Hg has been found to be higher amongst crematoria staff than in a control population, and exposure to fine particulates may occur, particularly where there are no operational and engineering controls to reduce exposure to dust.[44,45] A recent occupational exposure study following the cremation of a deceased patient treated with a radiopharmaceutical Lutetium-177 (Lu^{177}) found no trace of the radioactive substance in the urine of the crematorium operator but detected radiation within the crematorium and presence of another isotope in the employee's urine, suggesting possible exposure on a previous occasion.[9]



3. What is standard practice for siting of crematorium in proximity to residential areas?

Table 1 identifies the many factors affecting emissions from crematoria. Ground level concentrations can also be affected by local prevailing wind direction and topography. In North America, there are no standard requirements for crematoria setback distances and no minimum separation distances are set at a federal level in either the US or Canada. Crematoria are regulated at the provincial/territorial level and regional or municipal authorities determine whether minimum setbacks are required based on relevant planning and environmental considerations. The literature search for public agency resources and grey literature identified many different practices, with some selected examples from around the world listed in Table 3.

TABLE 3. SELECTED EXAMPLE SETBACK DISTANCES FOR CREMATORIA FROM AROUND THE WORLD

England and Wales (UK Cremation Act)[46]	200 yards (183 m) between a crematorium and any dwelling house and 50 yards from a public highway to protect residents from nuisance smoke and fumes and provide privacy to funeral proceedings
West Australia[47]	200-300 m between crematoria and sensitive land uses
South Australia and the Australian Capital Territory[48,49]	150 m minimum separation distance
South Africa, Department of Health[50]	500 m from any habitable building
US (Sacramento County, California)[51]	500 feet (152 m) from any agricultural-residential, residential, or interim residential zoning district

In Canada, there is a range of local zoning practices establishing permitted and prohibited locations for crematoria as well as other restrictions or specifications for setback distances. For example, in Ontario, the minimum separation distances (MSD) and the potential area of influence (AOI) for crematoria depend on whether the local permitting authority classify a crematorium as a Class 1 (e.g., MSD of 20 m, and AOI of 70 m) or Class 2 facility (e.g., MSD of 70 m, and AOI of 300 m).[40,52] Elsewhere, crematoria may be permitted in conjunction with a cemetery or in specified zones (Industrial) with minimum separation distances between crematoria and sensitive receptors such as schools, daycares, libraries, or care facilities (e.g., 30-60 m).[53,54] Setback distances are not specified in all jurisdictions, and in these places, the siting of crematoria may be at the discretion of local authorities.

4. What steps can be taken to minimize crematoria emissions to reduce exposure risks?

While there are limited studies on the health effects due to crematoria emissions specifically, the wider body of literature on the negative health effects due to exposure to substances such as PCDD/Fs, Hg and $PM_{2.5}$ indicate that best practice measures should be adopted to minimize the risk of exposure to these pollutants. In addition to local planning and zoning bylaws, regulation of crematoria varies by province, with oversight government authority ranging from consumer protection to environment or public health ministries. Typically, ambient air quality monitoring around crematoria is unlikely to be required due to the small size of the installations and the need to comply with other specific regional requirements for crematoria.

In BC, the provincial regulator of crematoria is Consumer Protection BC, under The Cremation, Internment and Funeral Services Regulations. The Regulations require an initial engineering report to support operation of a crematorium, certifying that the crematorium complies with manufacturer's specifications, local bylaws, and provincial laws (see Crematory Technical Checklist). The Regulations also prohibit the use of plastics, fiberglass, foam, Styrofoam, rubber, PVC and Zn in funeral containers to reduce harmful emissions.[55] In Ontario, Environmental Compliance Approval through the Ministry of Environment, Conservation and Parks is required prior to replacement or construction of human and pet crematoria to address concentrations of air pollutants on and beyond a cemetery property under normal operations. Conditions of operation and limits for emissions and potential nuisance from odour or noise may be placed on the crematoria to minimize local impacts. This can include continuous monitoring for parameters such as CO, as an indicator of combustion efficiency, which can affect the emissions of organic pollutants. In the Northwest Territories, under proposed elements for the Cremation Regulations, the Chief Public Health Officer will consider applications for crematoria and determine if proposed processes are safe. Applicants will be required to provide equipment specifications, design features, operational methods, control measures for reducing exposure to harmful microorganism and chemical hazards, and additional treatment processes.[56] In Quebec, the *Environmental Quality Act* Clean Air Regulation sets specific requirements for crematoria including device design and operational parameters. Monitoring measures are also specified, with a requirement to test emissions of gases into the atmosphere and calculate particulate concentration within a year of installation, and at least once every five years thereafter.[57]

BEST PRACTICE GUIDELINES

The Secretariat of the Stockholm Convention on Persistent Organic Pollutants has published best practice guidelines for crematoria.[33] These align with other recommendations cited throughout the literature.[19] The key recommendations include:

- Minimum furnace temperature (850 °C), residence time in the second chamber (2 seconds for combustion gases) and enough air (e.g., 6% O_2 by volume) to ensure combustion in the second chamber and avoid generating products of incomplete combustion;
- Suitable air pollution control equipment, which could include temperature controls, dust control, carbon injection, fabric filtration, air tightness of combustion chambers and casings;
- Monitoring of gas temperature and flue gas O_2 and CO concentrations, application of relevant emission limit values and additional monitoring, including ambient monitoring of soil and air in the proximity of crematoria;
- Avoidance of use of PVC, metals and chlorinated compounds in coffins and fittings;
- Operational controls, inspection and preventive maintenance.

Additional legislative measures can be effective in reducing emissions. For example, In Europe, Hg emissions from crematoria were reduced following the implementation of Hg abatement requirements.[23] Other good practice measures to protect crematoria workers, such as removal of radioactive implants before cremation, informing crematoria workers of recent radiotherapy treatments for deceased patients, and safe handling practices for ashes, can also reduce possible environmental releases of pollutants.[3,18,44] The removal of dental amalgams prior to cremation has been proposed as a measure to significantly reduce emissions of Hg but may be difficult to impose.

A summary of the influence of various control measures on the key pollutants of interest is presented in Table 4.

TABLE 4. EFFECTIVENESS OF VARIOUS CONTROL MEASURES ON REDUCING POLLUTANT RELEASE FROM CREMATORIA

	PCDD/Fs	Hg	$PM_{2.5}$	Radioactivity
Source control				
Removal of plastics, etc.	✓		✓	
Non-toxic and eco-friendly coatings or materials in caskets	✓			
Removal of Hg fillings		✓		
Removal of medical devices containing radioactive substances				✓
Operational controls				
Minimum 850°C (2nd chamber)	✓		✓	
Minimum residence time of 2 s (2nd chamber)	✓		✓	
Adequate O_2 in combustion chamber	✓		✓	
Monitoring CO releases	✓		✓	
Air tightness of combustion chambers and casings	✓	✓	✓	✓
Maintenance and inspection	✓	✓	✓	✓
Operator training	✓	✓	✓	✓
Emissions controls				
Dust control (filters and scrubbers)	✓		✓	
Activated carbon treatment	✓	✓		
Hg removal technology (binding, precipitation etc.)		✓		
Adequate chimney height	General dispersion and dilution of pollutants higher into atmosphere			

✓ indicates the measure can help reduce emissions

SUMMARY

Combustion processes can generate potentially harmful pollutants such as organic compounds (PCDD/Fs), Hg, and fine particulates ($PM_{2.5}$). While these substances have been associated with a range of adverse health effects, no studies have been found that show causal links between crematoria emissions and adverse health effects. The absence of emissions data for crematoria and ambient air quality monitoring in the vicinity of installations limits the ability to fully assess exposures and health impacts. A precautionary approach could be adopted that includes following best practice recommendations for design, operation, monitoring and maintenance of crematoria.

There is no standard practice across Canada for emissions controls, monitoring or crematoria setback distances, but there are specific requirements set at regional and local levels. Appropriate setback requirements and other controls should consider equipment type, size, number of proposed cremations, local climate conditions, local land use and zoning and proximity to sensitive receptors on a case-by-case basis. Communication with the public about potential impacts and risk reduction strategies early in the development process can help to address concerns and inform appropriate siting, operational controls and monitoring.

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