Performance Measurement Evaluation for Risk Management of Dioxins and Furans (Health Component)

Executive Summary:

This report measures and evaluates the performance of risk management strategies and tools taken to help protect Canadians from exposures to polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans (also known as and hereafter referred to as dioxins and furans) that were found to pose a risk to human health and the environment. Dioxins and furans were selected for performance measurement evaluation because key baseline and performance indicator data are available, and human health risk management tools have been in place for a sufficient amount of time to measure impact.

Dioxins and furans were assessed by the Government of Canada in 1990, where they were found to be a possible risk to human health and the environment, and met the criteria for toxic under paragraphs 11(a) and 11(c) of the *Canadian Environmental Protection Act, 1988* (CEPA 1988).. Risk management strategies and tools were established to help reduce dioxin and furan exposures to the environment and to the general population in Canada through actions targeting releases from pulp and paper mills, metal production, waste incineration, and wood preservation industries. The Government of Canada is also a signatory party to several international agreements focused on the reduction of levels of dioxins and furans among other persistent organic pollutants.

Information collected by the Government of Canada shows that since these risk management strategies and tools came into effect, there has been a reduction in:

1. Levels of dioxins and furans emitted to, and measured in, outdoor air;
2. Concentrations in foods of animal origin and, as a result, dietary exposure to, dioxins and furans; and
3. Concentrations of dioxins and furans measured in human milk.

Overall, risk management tools pertaining to human health are meeting their intended goals, and progress has been made towards virtual elimination of dioxins and furans.

Contents

1. About Performance Measurement

The Government of Canada is conducting performance measurement evaluations on the risk management of toxic substances to ascertain whether actions taken to help protect Canadians and their environment are meaningful and effective over time. Performance measurement evaluation will help determine how well the risk management actions have reduced or eliminated the risk associated with substances concluded toxic under the *Canadian Environmental Act, 1999* (CEPA). Adjustments may be required when risk management strategies and tools are not achieving the desired outcome.

The Government of Canada establishes goals in order to help protect Canadians and their environment from risks posed by toxic substances. The Government of Canada aims to achieve these goals by setting human health, environmental and/or risk management objectives, and developing a strategy to meet those objectives. Performance measurement assesses how risk management actions contribute to protecting Canadians and their environment from toxic substances, and identifies areas of improvement to be addressed moving forward.

The intent of this document is to evaluate the dioxins and furans risk management strategy from a human health perspective.

2. Background

Polychlorinated dibenzo-*para*-dioxins and polychlorinated dibenzofurans, referred to throughout as dioxins and furans, are groups of chemicals that typically form as by-products of combustion processes. All dioxins have the same basic chemical structure, with chlorine atoms substituted at different locations (Figure 1). Furans are similar, with a different base structure. Each individual compound or "congener" has its own CAS RN[1], though dioxins and furans are often emitted as a mixture of several different congeners. The level of toxicity of an individual dioxin or furan congener varies according to its structure. For this reason, modified toxic equivalency factors (TEF, which replaced the older "International Toxicity Equivalent Factors", I-TEF) have been derived in order to be able to assess the overall toxicity of mixtures of dioxins and furans (van den Berg et al., 2006).

Dioxin-like polychlorinated biphenyls (dl-PCBs, a third group of structurally distinct chemicals) are often considered together with dioxins and furans for health assessments. These substances were assessed separately from dioxins and furans, with separate risk management actions, and as such will be covered in a separate performance measurement and evaluation report for polychlorinated biphenyls.

[1] The Chemical Abstracts Service Registry Number (CAS RN) is the property of the American Chemical Society and any use or redistribution, except as required in supporting regulatory requirements and/or for reports to the Government of Canada when the information and the reports are required by law or administrative policy, is not permitted without the prior, written permission of the American Chemical Society.

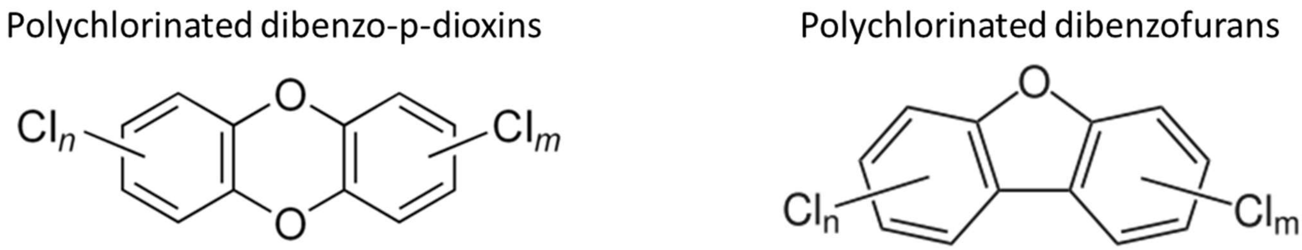

Figure 1. Base structures of polychlorinated dibenzo-*p*-dioxins (referred to as dioxins) and polychlorinated dibenzofurans (referred to as furans).

Dioxins and furans are by-products and have no useful applications. Chemical sources (such as wood treatments and pesticides), intentional combustion activities (such as waste incineration and fuel burning), and industrial sources (such as pulp and paper mills and metal production) were identified in the 1990 Government of Canada assessment as the main activities that result in releases of dioxins and furans to the environment. A notable amount of dioxins and furans are also believed to be present in the environment as a result of wildfires and other uncontrolled combustion sources (Dwyer & Themelis, 2015). In 1990, municipal waste incinerators, the wood preservative pentachlorophenol, and pulp and paper mills using chlorine in the bleaching process were considered to be the most significant sources of dioxins and furans (Government of Canada, 1990).

Dioxins and furans are released to air, water, and soil. Due to their persistence and mobility in the environment, detectable amounts of dioxins and furans have been measured in areas that have no known local sources of these substances such as the Arctic and polar regions. Their lipophilic nature also means that these substances dissolve readily in fats and can bioaccumulate and biomagnify in the food web. As a result, foods of animal origin are estimated to represent over 90% of human exposures to dioxins and furans from all sources (EFSA Panel on Contaminants in the Food Chain et al., 2018). Dioxins and furans reside mainly in the body fat of humans, and can take many years to break down in the body given the estimated half-life of seven years in humans (Pirkle et al., 1989). For this reason, the body-burden of dioxins and furans, measured as their concentration in body fat, is often used to measure the accumulated level of exposure of a population to dioxins and furans.

There are several health effects that may be associated with exposure to high levels of dioxins and furans, including:

- skin disorders, such as chloracne (Panteleyev & Bickers, 2006)
- disruption of male reproductive function (Mocarelli et al., 2008)
- altered liver metabolism (Neuberger et al., 1999)
- impacts on thyroid function (Baccarelli et al., 2008)
- certain types of cancers (IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, 2012)
- developmental effects including neurotoxicity (Tai et al., 2013)

The original Priority Substance List (PSL) risk assessment, carried out in 1990, concluded that dioxins and furans met the requirements to be considered “toxic” under paragraphs 11(a) and 11(c) of the *Canadian Environmental Protection Act, 1988* (CEPA 1988), equivalent to paragraphs 64(a) and 64(c) of CEPA 1999 (Government of Canada, 1990). It was noted that breast-fed infants and those consuming highly contaminated fish may have had exposures that approached or exceeded the tolerable daily intake (TDI, the amount of a substance in food an individual could be exposed to daily over a lifetime without appreciable health risk). It is important to mention, however, that the original risk assessment stated that the known health benefits of breastfeeding outweighed any potential health risks due to dioxin and furan intake (Government of Canada, 1990).

In July 1998, the Government of Canada announced that dioxins and furans were to be classified as Track 1 substances (slated for virtual elimination) under the Toxic Substances Management Policy (TSMP), due to their persistence, potential for bioaccumulation, and their presence resulting primarily from human activity (Government of Canada, 1998).

Dioxins and furans have been selected for performance measurement evaluation because key baseline and performance indicator data are available for this group of substances and sufficient time has passed since many of the risk management tools were implemented to measure their performance. The ultimate objective for this group of substances is virtual elimination in Canada. This performance measurement evaluation aims to report on the progress made to date with the reduction of potential exposures achieved through risk management measures in place to protect the health of Canadians. In addition, this performance measurement evaluation aims to identify whether any adjustments to existing risk management actions may be warranted.

3. Risk Management Approaches

Several risk management actions have been put in place to help mitigate risks posed by dioxins and furans, as shown in Table 1.

3.1 Domestic Risk Management Actions

Table 1. Summary of domestic risk management actions.

Year	Title of risk management action	Sector
1992	*Pulp and Paper Mill Defoamer and Wood Chip Regulations*	Pulp and Paper mills
1992	*Pulp and Paper Mill Effluent Chlorinated Dioxins and Furans Regulations*	Pulp and Paper mills
1999	The Pest Management Regulatory Agency’s Strategy for Implementing the Toxic Substances Management Policy (TSMP)	Pest Control Products
2001	Environmental Code of Practice for Non-Integrated Steel Mills	Metal production

2001	Environmental Code of Practice for Integrated Steel Mills	Metal production
2001	Canada-Wide Standard for Waste Incinerators	Waste incineration
2001	Canada-Wide Standard for Coastal Pulp and Paper Boilers	Pulp and Paper mills
2003	Canada-Wide Standard for Iron Sintering	Metal production
2003	Canada-Wide Standard for Steel Manufacturing Electric Arc Furnaces	Metal production
2003	Canada-Wide Standard for Conical Waste Combustion of Municipal Waste	Waste incineration
2004	Recommendations for the Design and Operation of Wood Preservation Facilities	Wood preservation
2005	Pollution Prevention Planning Notices – Wood Preservation Facilities	Wood preservation
2006	Pollution Prevention Planning Notices – Base Metals Smelters and Refineries and Zinc Plants	Metal production
2006	Environmental Code of Practice for Base Metals Smelters and Refineries	Metal production

3.1.1 Regulations

Pulp and Paper Mill Defoamer and Wood Chip Regulations (1992)
This regulation limits the concentration of dioxins and furans at ≤40 ppb by weight of furans and ≤10 ppb by weight for dioxins in defoamers manufactured, imported, offered for sale to, or used by pulp and paper mills. The regulation also prohibits the importation, offer for sale, sale, and use of wood chips treated with polychlorinated phenols in a pulp and paper mill. Testing and reporting requirements are included in the regulation.

Pulp and Paper Mill Effluent Chlorinated Dioxins and Furans Regulations (1992)
This regulation prohibits the release of measureable concentrations of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin or 2,3,7,8-tetrachlorodibenzofuran (the two most toxic dioxin and furan compounds) in pulp and paper mill effluents. The implementation of both *Pulp and Paper Regulations*, combined with provincial regulatory initiatives, resulted in a reduction of aquatic releases of dioxin and furans of greater than 99% by 1997 (Commission for Environmental Cooperation, 2011).

3.1.2 Environmental Codes of Practice

Environmental Code of Practice for Non-Integrated Steel Mills (2001)
The code identifies the minimum performance standards for new steel mills and provides a set of performance goals that existing mills can strive to achieve through continual improvement over time. The non-integrated mills segment of the steel sector includes all facilities that use scrap steel and direct reduced iron as raw materials to produce primary steel products. There were twelve non-integrated steel mills in Canada at the time of this instrument's implementation.

Environmental Code of Practice for Integrated Steel Mills (2001)
The code identifies the minimum performance standards for new steel mills and provides a set of performance goals that existing mills can strive to achieve through continual improvement over time. The integrated mills segment of the steel manufacturing sector includes all facilities that use coal and iron ore or agglomerated iron ore as raw materials to produce primary steel products. There were four integrated steel mills in Canada at the time of its implementation.

Environmental Code of Practice for Base Metals Smelters and Refineries (2006)
The code identifies and promotes recommended practices as requirements for new facilities, and as goals for existing facilities.

Recommendations specific to dioxins and furans emission guidelines:
1. Each existing facility should be designed and operated to limit release concentrations of dioxins and furans to less than 100 pg TEQ*/Rm^3.
2. Each new facility should be designed and operated to limit release concentrations of dioxins and furans to less than 32 pg TEQ*/Rm^3.
Note – Rm^3 refers to reference conditions defined as volumes at 25°C (298.15°K) and 101.3 kPa, dry gas basis.

3.1.3 Canada-Wide Standards (CWS)

Canada-wide Standards (CWS) are intergovernmental agreements developed under the Canadian Council of Ministers of the Environment (CCME). CWS flow from a political commitment by federal, provincial and territorial Ministers to address key environmental protection and health risk issues that require concerted action across Canada. Five CWS have been implemented for dioxins and furans, targeting five major sectors that accounted for 65% of national releases of dioxins and furans in 1999. Reviews of the CWS were conducted several years after implementation to measure their progress, with the latest available review of progress occurring in 2009. A brief description and summary of the evaluations for each of the five CWS are provided below. Copies of the actual CWS can be requested from the CCME webpage.

Canada-Wide Standard for Waste Incinerators (2001)
This CWS sets out maximum concentrations for exhaust gases from new or expanding waste incineration facilities of any size. The standard encourages applicants to use the best available pollution prevention and control techniques, such as implementing waste diversion programs. By 2009, all but one type of incinerator achieved compliance with this CWS (CCME, 2009). As of 2017, the facility that operated that incinerator has switched to a newer technology resulting in compliance of the CWS.

Canada-Wide Standard for Coastal Pulp and Paper Boilers (2001)
This CWS sets out numeric targets and timeframes for reducing emissions from new and existing boilers. The second component sets out a process for further examining pollution prevention opportunities to prevent the creation of dioxins and furans. All facilities conformed with this CWS in 2008, but there were large variations of individual test results

noted. Total emissions from this sector declined from 10.5 g TEQ /year in 1995 to 1.5 g TEQ/year in 2008 (CCME, 2009).

Canada-Wide Standard for Iron Sintering (2003)
This CWS for the iron sintering sector consists of two components. The first component sets out numeric targets and timeframes for reducing emissions of dioxins and furans from new and existing iron sintering plants. The second component sets out a process for further examining pollution prevention opportunities to prevent the creation of dioxins and furans. The only iron sintering plant operating in Canada at that time shut down in 2007.

Canada-Wide Standard for Steel Manufacturing Electric Arc Furnaces (2003)
This CWS stipulates all new, modified and existing furnaces undergo annual emissions testing to verify compliance with the limits and to increase the knowledge of these emissions in the sector. Only one non-conforming facility was identified in 2008.

Canada-Wide Standard for Conical Waste Combustion of Municipal Waste (2003)
This CWS proposes to phase out the operation of conical waste combustors in Newfoundland and Labrador, and prevent the operation of new conical waste combustors anywhere in Canada. Any new incinerators are also considered in the CWS for dioxins and furans emissions from incinerators. As of fall 2009, 42 out of 58 conical waste combustors servicing 165,378 people were closed, which resulted in a 76.3% reduction of releases of dioxins and furans to air from this sector (CCME, 2009).

3.1.4 Pollution Prevention (P2) Planning Notices

Recommendations for the Design and Operation of Wood Preservation Facilities (2004) and Pollution Prevention Planning Notice - Wood Preservation Facilities (2005)
The *recommendations document* for the design and operation of wood preservation facilities aimed to reduce the release of targeted toxic substances (including dioxins and furans) during wood preservation processes to the lowest achievable levels through adoption of best management practices. The risk management objective of the Pollution Prevention Planning Notice was to reduce the release of dioxins and furans during wood preservation processes to the lowest achievable levels by the application of (or achieving equivalence with) the practices set out in the *recommendations document*. The Notice has been successful. Although compliance with the Pollution Prevention Planning Notice was difficult to achieve, three of four facilities eventually met their objectives. The other facility closed.

Pollution Prevention Planning Notices - Base Metals Smelters and Refineries and Zinc Plants (2006)
This notice required facilities to consider recommendations from the Strategic options for the management of toxic substances from the base metals sector and to prepare pollution prevention plans for a variety of emissions including dioxins and furans, arsenic, cadmium, lead, mercury and nickel. One facility was identified as needing to meet an annual release target of 0.5 grams I-TEF by 2008. From 2005 to 2015, facilities from this

sector reported a 65% (0.69 g I-TEQ) reduction in emissions of dioxins and furans, and the identified facility met the 2008 target for dioxins and furans emissions.

3.1.5 Other Domestic Actions

Food and Livestock Feed

Health Canada establishes prohibitions and maximum levels (MLs) for chemical contaminants in food in Part 1 and Part 2, respectively of the *List of contaminants and other adulterating substances in foods*. A review of the existing prohibition for TCDD (tetrachlorodibenzodioxin, the most hazardous dioxin congener) in all foods except fish, and of the ML for TCDD in fish, was initiated. The prohibition was established before the advancements in analytical methodology to detect trace amounts of dioxins and furans in foods. Further, the ML was established before the current approach to take into account the toxic equivalency of dioxins, furans, and dioxin-like PCBs. This means that introduction of lower ML values are now feasible. Health Canada regularly monitors the concentrations of various chemicals, including dioxins and furans, in foods in its ongoing Total Diet Study and through targeted surveys as part of its risk assessment and risk management activities related to these compounds in foods.

There are also action levels on concentrations of dioxins and furans in livestock feed ingredients under the *Feeds Act* and *Feeds Regulations*. Livestock feeds represent an important source of contamination in foods of animal origin and prevention of exposure through feed contributes to reducing human exposure (Scientific Committee on Animal Nutrition, 2000; Codex Alimentarius Commission, 2006). The Canadian Food Inspection Agency (CFIA) conducts regular monitoring of dioxins and furans in foods and livestock feed ingredients and has established a dioxin trace-back program whereby elevated levels of these contaminants found in foods of animal origin (e.g., meat, dairy, or eggs) triggers analyses of feed batches. As part of the CFIA's Feed Regulatory Modernization Project (updating the Canadian Federal *Feeds Regulations*), CFIA has updated and established maximum levels of certain contaminants allowed in livestock feeds. This includes proposing maximum levels of dioxins and furans for certain livestock feed ingredients – an important measure as products of animal origin are the largest source of dioxin and furan exposure to humans. These apply to feeds manufactured in Canada and feeds imported for domestic use.

On-Site Combustion of Residential Waste

In 2002, the Canadian federal government sponsored "Burn it Smart", a public information program intended to reduce wood smoke pollution. In addition, numerous jurisdictions in Canada have implemented regulations or undertaken educational programs to reduce combustion of residential waste, which was found to be prevalent in remote and northern communities, and was significantly contributing to releases of dioxins and furans to the environment.

Pest Control Products:

Dioxins and furans are not registered as active ingredients or formulants in pest control products, and are only present unintentionally as microcontaminants. Contaminants are regulated as part of the pest control product under the *Pest Control Product Act*

(PCPA).The Pest Management Regulatory Agency's (PMRA) approach to managing dioxins and furans is outlined in the Regulatory Directive: The Pest Management Regulatory Agency's Strategy for Implementing the Toxic Substances Management Policy (DIR99-03). Batch analysis data is required for all pesticides that are known or suspected to contain dioxins and furans prior to registration and during re-evaluations. This ensures the acceptability of the pest control product before it enters the Canadian market and its continued acceptability once on the market. Any pest control product found to have unacceptable levels of dioxins and/or furans is not permitted. PMRA works in partnership with registrants to reduce and/or eliminate dioxins and furans in line with the best available technology from a manufacturing perspective. Analyses include all 17 congeners with a limit of detection (LOD) at the ppt level.

St. Lawrence Action Plan:
Concerns about various pollutants in the St Lawrence hydrographic system were noted in the early 1970s, and led to the inception of the first St. Lawrence Action Plan in 1988. Dioxins and furans were one of ten priority substances that were identified at that time. This Canada-Quebec collaboration that also included various other stakeholders had, as an objective, to conserve, restore, protect, and develop the St. Lawrence. There have been several successive St. Lawrence Action Plans developed, and the levels of dioxins and furans measured have been reported to be reduced by 92% in 1998 (Government of Canada & Gouvernement du Québec, 1998). From 2001 to 2013, dioxin and furan concentrations in certain types of fish in the St. Lawrence were relatively stable, remained low, and were not deemed to pose a major risk to human health (Government of Canada & Gouvernnement du Québec, 2016).

International Risk Management:
As exposure to these compounds can occur at great distances from their origin, to ensure the continued protection of Canadians and their environment, Canada is an active participant in several international agreements on persistent organic pollutants (POPs).

Agreements include:

- the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, signed in 1989;
- the United Nations Economic Commission for Europe Protocol to the 1979 Convention on Long-range Transboundary Air Pollution on Persistent Organic Pollutants, signed in 2001 (known as the 1998 Aarhus Protocol or the POPs Protocol); and
- the United Nations Environment Program (UNEP) Stockholm Convention on Persistent Organic Pollutants, signed in 2001.

Canada is also committed to reducing dioxins and furans releases through several regional initiatives such as:

- the North American Commission for Environmental Cooperation - the Mercury and Dioxins/Furans/Hexachlorobenzene Action Plans;
- the Canada-U.S. Great Lakes Binational Toxics Strategy; and
- the Northern Contaminants Program.

International cooperation and capacity building is a key component in the risk management of these substances.

4. Performance Measurement Indicators

The Government of Canada measures the presence of dioxins and furans in the environment, in foods of animal origin, and through human biomonitoring to help ensure that Canadians are protected. These measurements are used as indicators to help evaluate the different risk management actions taken to reduce human exposure to these harmful chemicals.

4.1 Environment

4.1.1 Environmental Releases by Industry – National Pollutant Release Inventory (NPRI)

The NPRI is Canada's public inventory of releases, disposals, and transfers. The NPRI collects information on pollution from facilities in categories that include releases to air, water, or land. Environmental releases of dioxins and furans have been published by the NPRI since 2000. This inventory provides the government and Canadians with release data on a Canada-wide and facility-by-facility basis, for facilities that meet the reporting requirements and conduct specified activities. This is an important data source for the performance measurement and evaluation of dioxins and furans, given that their creation is almost entirely from large-scale industrial activities. From 2000 – 2006, facilities were required to report the total emitted dioxins and furans in 1988 TEQ units. From 2007 onwards, facilities were also required to report quantities of each of the 17 individual toxic dioxins and furans (if they have the information required to do so). To ensure consistency, all NPRI data is shown in 1988 TEQ units. NPRI data was used to show the overall releases to air, water, and land nationally, and by province and sector.

4.1.2 Releases to Air – Air Pollutant Emission Inventory (APEI)

Canada's APEI is a comprehensive inventory of air pollutants at the national, provincial, and territorial level, maintained by Environment and Climate Change Canada (ECCC). The APEI compiles emissions of several different air pollutants including total dioxins and furans. The APEI uses several data sources in their estimation, including data obtained by the NPRI program (described above), combined with well-documented science-based estimation tools. Emissions of dioxins and furans have been tracked in the APEI since 1990, and the most recent APEI report published in 2020 includes data up to 2018 (Environment and Climate Change Canada, 2020). This data was used to show the emissions to air nationally, as well as by province and by sector.

4.1.3 Ambient Air Concentrations – National Air Pollution Surveillance (NAPS) Program

The NAPS program provides accurate and long-term air quality data across Canada. NAPS is managed by a cooperative agreement among the provinces, territories, and municipal governments. Ambient air levels of dioxins and furans were measured by the NAPS network of monitors from 1989 to 2011. Data collected, compiled, and analyzed by this program provides the government and Canadians with information on the concentrations of dioxins and furans in ambient air from many different sites across the country. This data was used to investigate trends in the concentrations of dioxins and furans in ambient air. Since there are many monitoring stations that may have measured these substances at various times and frequencies throughout the year, the measurements within each monitoring station was averaged, and then the monitoring station averages were used to calculate an annual average dioxin and furan concentration. Note that for cases where a congener was found below its limit of detection, the concentration was set at the detection limit.

4.2 Dietary intake

4.2.1 Concentrations in Food – Total Diet Study

Since the 1990s, Health Canada and the CFIA have implemented a number of ongoing surveillance programs that regularly monitor the levels of chemical contaminants in the food supply, including dioxins and furans. CFIA food surveillance programs for dioxins and furans include targeted surveys as well as the National Chemical Residue Monitoring Program (NCRMP), which has analyzed approximately 400 samples each of domestic raw milk, imported and domestic eggs, and domestic meat for dioxin and furan content. One of Health Canada's main surveillance programs is the Canadian Total Diet Study (TDS), which measures the concentrations of a variety of chemical contaminants in foods typical of the Canadian diet. This is of particular importance for dioxins and furans as humans are primarily exposed to these substances through the diet, making this data a key performance indicator.

4.3 Biomonitoring

4.3.1 Concentrations in Breastmilk

The Government of Canada has measured concentrations of dioxins and furans in human milk since the early 1980s through five surveys (John J. Ryan et al., 1993; John J. Ryan & Rawn, 2014 Rawn et al., 2017). These measurements provide an indication of levels of *in utero* exposures, and dietary exposures for children who are breastfed. Given that dioxins and furans eventually reach a steady state body burden in adult age, and because these measured concentrations are related to their concentration in the body fat and blood of the mother, they are a valid indicator for the accumulated concentration in women of reproductive age (D. G. Patterson et al., 1988; Wittsiepe et al., 2004). Further, as the concentration of dioxins in body fat of men and women do not differ (Donald G. Patterson et al., 2008; Consonni et al., 2012), these body burden measurements tend to reflect the chronic dioxin and furan exposure of the general population as well.

4.3.2 Concentration in Blood – National Biomonitoring Program

Health Canada's National Biomonitoring Program monitors concentrations of environmental chemicals in the Canadian population. This information is collected in partnership with Statistics Canada through the Canadian Health Measures Survey (CHMS). The CHMS is an ongoing survey that evaluates the general health of Canadians through household interviews, physical examinations, and biological specimen collection. Dioxins and furans were measured in blood serum samples of Canadians aged 6 to 79 years in CHMS cycle 1 (2007-2009) and of those aged 3 to 79 years in CHMS cycles 3 (2012-2013), 4 (2014-2015), and 5 (2016-2017). Groups of around 57-120 blood serum samples from survey participants of the same sex and age group were pooled together due to the resource-intensive nature of the dioxin and furan analysis. Results from the National Biomonitoring Program is used to establish baseline levels of dioxins and furans in the Canadian population, as well as to help determine the effectiveness of risk management actions in reducing exposures from all sources.

5. Key Performance Indicator Data

5.1 Environment

5.1.1 Environmental Releases by Industry – National Pollutant Release Inventory (NPRI)

Between the years 2000 and 2017, total industrial emissions to air, water, and land reported to NPRI were reduced from 100.1 g TEQ to 15.6 g TEQ, an 84.4% reduction (Figure 2). The time period of 2004 – 2006 saw the greatest decline in emissions, from 79.7 g TEQ to 41.0 g TEQ.

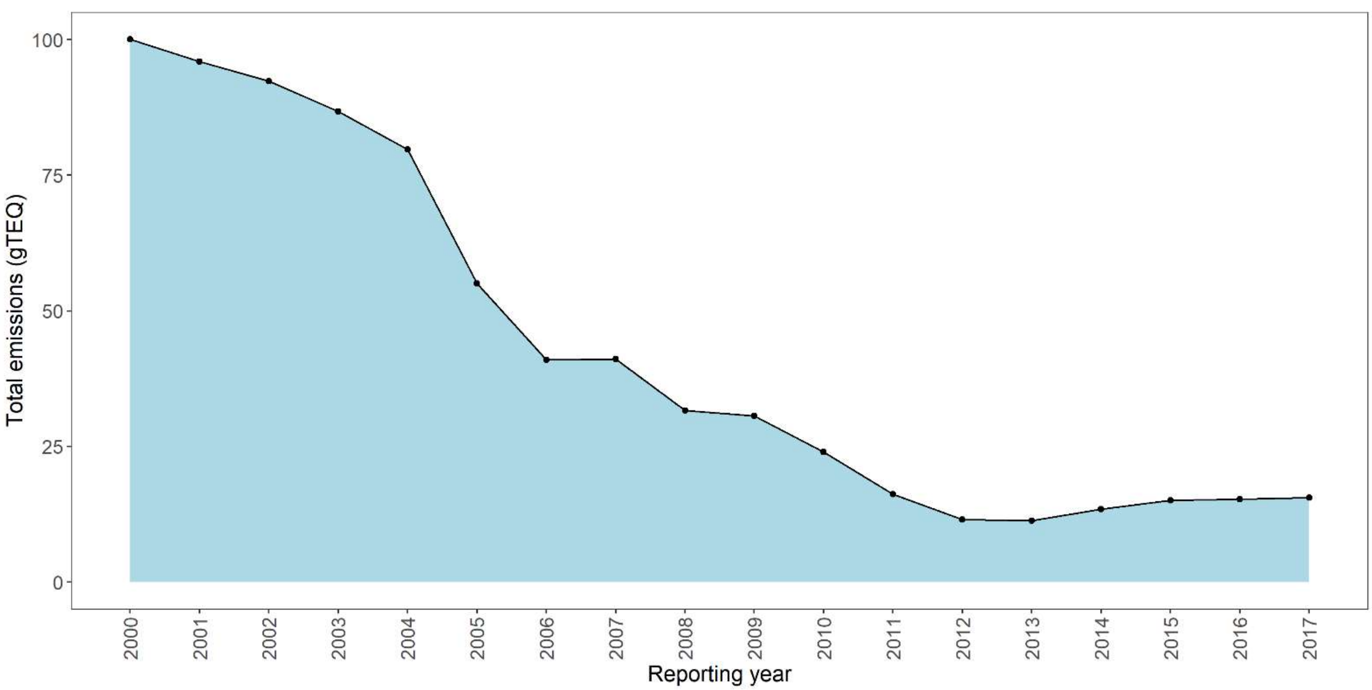

Figure 2. Total dioxin and furan emissions from facilities in all sectors in the NPRI datasets. Emission levels represent mandatory reporting from facilities across Canada from 2000-2017, measured in g TEQ 1988.

The national emissions of dioxins and furans reported to NPRI by industry are shown in Figure 3. The industries with the greatest absolute reductions were waste treatment and disposal (98% reduction), iron and steel (70% reduction), electricity (82% reduction), and aluminum (79% reduction). Data from 2017 shows the industries with the highest emissions of dioxins and furans were: iron and steel (5.6 g TEQ), pulp and paper (4.4 g TEQ), and electricity (1.9 g TEQ).

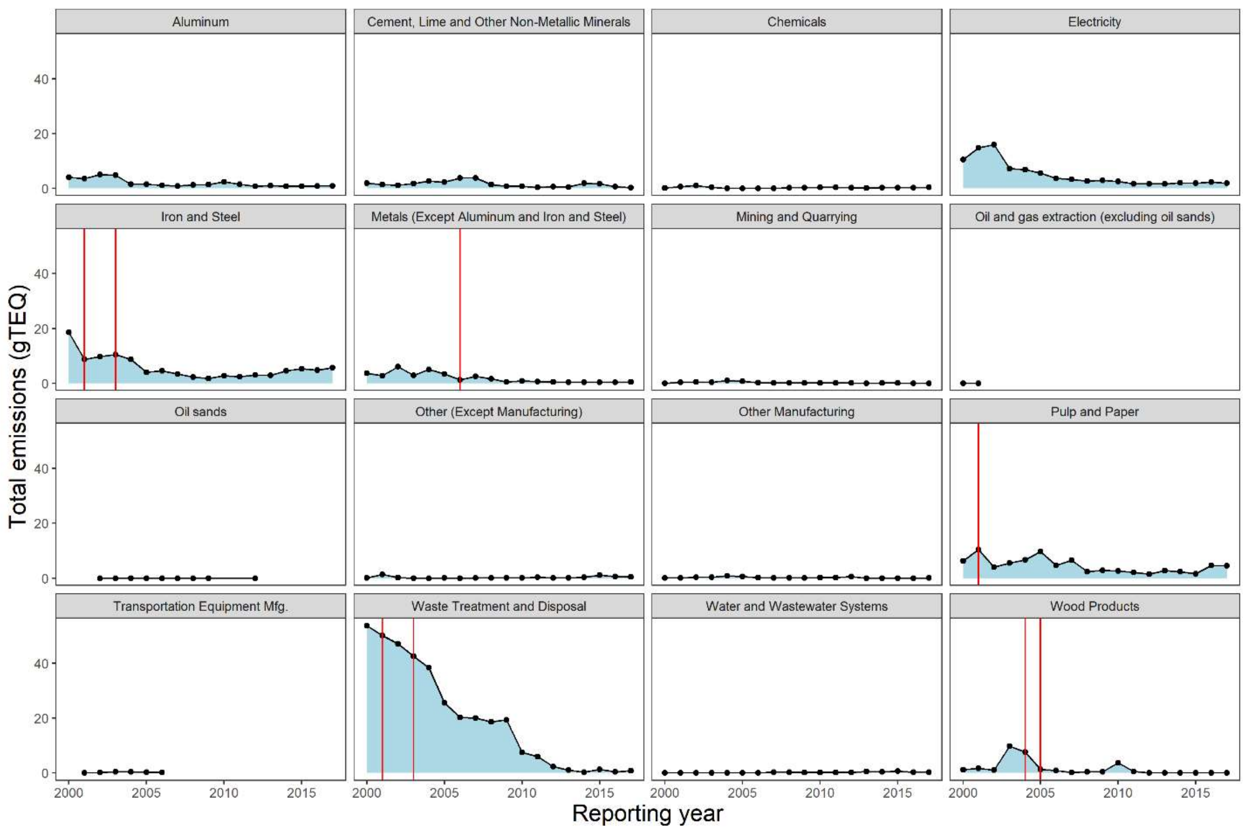

Figure 3. Total dioxin and furan emissions to air, water and land from facilities in all sectors reporting to the NPRI datasets, by sector. Emission levels represent mandatory reporting from facilities engaged in specific activities across Canada from 2000-2017, measured in World Health Organization (WHO) 1988 g TEQ. Vertical lines represent the implementation dates of the sector-specific risk management action, as listed in Table 1.

The reported emissions stratified by province are shown in Figure 4. Newfoundland and Labrador, as well as Ontario, had the greatest amount of dioxin and furan emissions in 2000, but by 2017, their emissions had reduced by 99% and 84% respectively. In 2017, the provinces with the highest total dioxin and furan releases reported by facilities were Ontario (4.3 g TEQ 1988) and British Columbia (4.0 g TEQ 1988).

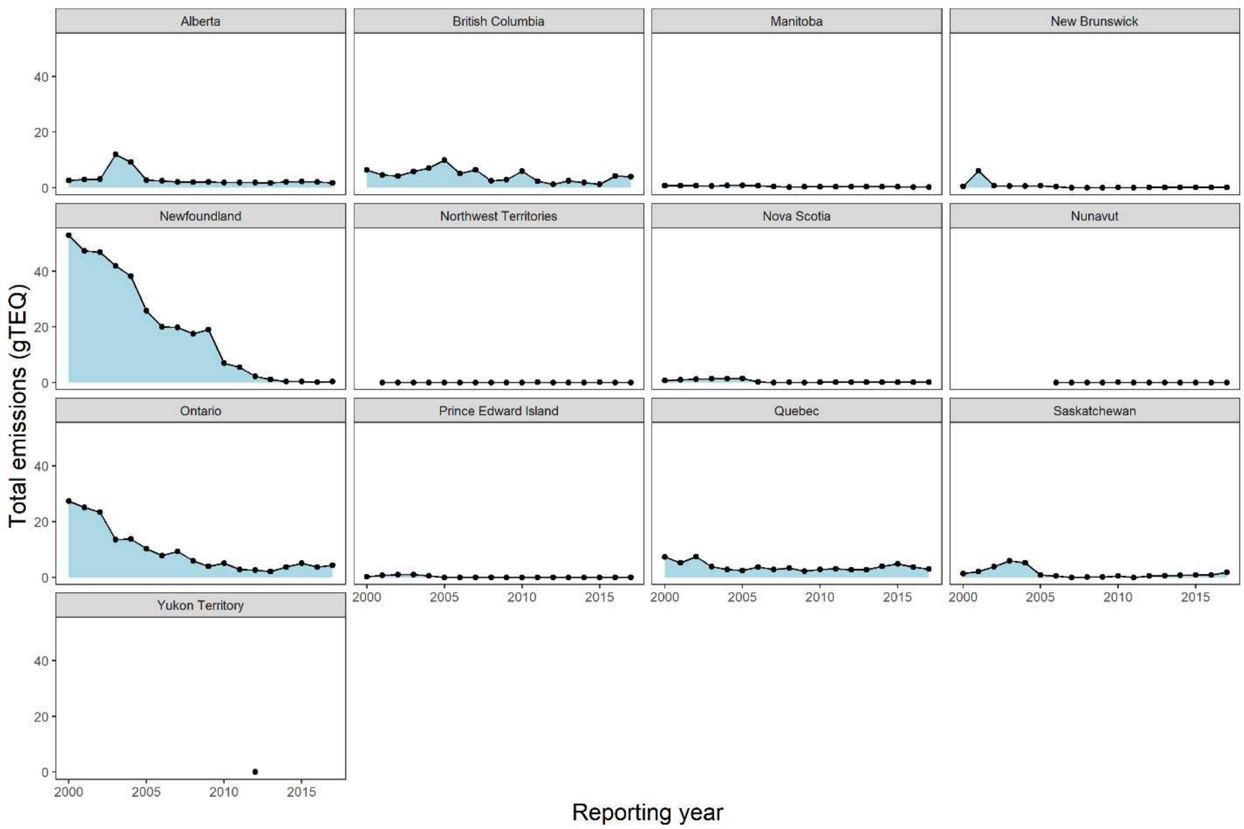

Figure 4. Total dioxin and furan emissions to air, water and land from facilities in all sectors reporting to the NPRI program, by province. Emission levels represent mandatory reporting from facilities across Canada from 2000-2014, measured in g TEQ 1988.

Looking more closely at the sector specific emissions for the two provinces with the highest emissions in 2000, Newfoundland and Labrador (Figure 5) and Ontario (Figure 6), there are some differences in emissions by sector. For Newfoundland and Labrador, emissions were entirely driven by waste treatment and disposal. In Ontario, electricity and metal production were the sectors that were responsible for most of the emissions of dioxins and furans.

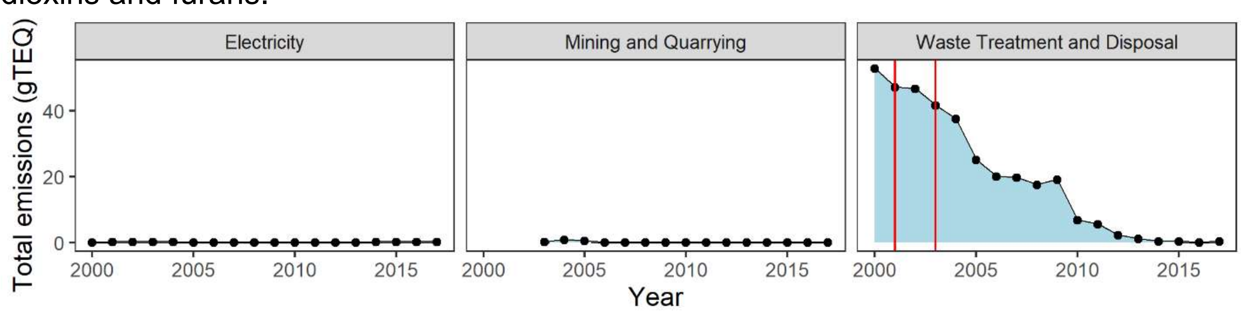

Figure 5. Emissions to air, water, and land in Newfoundland and Labrador by sector. Source: NPRI. Vertical lines represent the implementation dates of the sector-specific risk management action, as listed in Table 1.

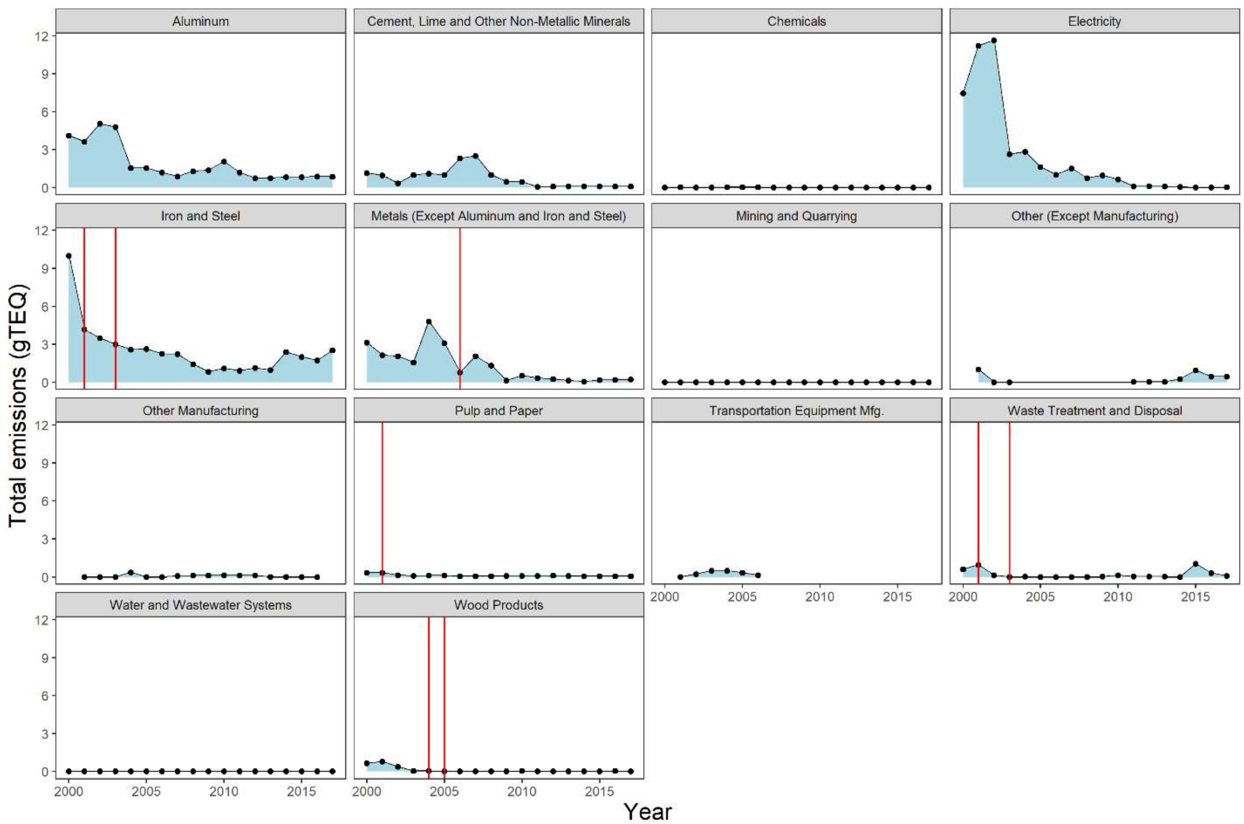

Figure 6. Emissions to air, water, and land in Ontario by sector. Source: NPRI. Vertical lines represent the implementation dates of the sector-specific risk management action, as listed in Table 1.

5.1.2 Releases to Air – Air Pollutant Emission Inventory (APEI)

Total emissions of dioxins and furans to air in Canada in 2018 as estimated by the APEI were approximately 73 grams of TEQ, an 84% reduction from the 451 g TEQ that were estimated to be emitted from all sectors in 1990. Incineration and waste sources accounted for the largest share of the decrease (from 346 g TEQ in 1990 to 24 g TEQ in 2018, a 93% reduction). The pulp and paper industry (from 11g TEQ to 1.1 g TEQ, 90% reduction), prescribed burning activities (from 7.6 to 0.5 g TEQ, 93% reduction), and the iron and steel industry (from 35 g TEQ to 7.1 g TEQ, 80% reduction), also showed large reductions in dioxin and furan emissions.

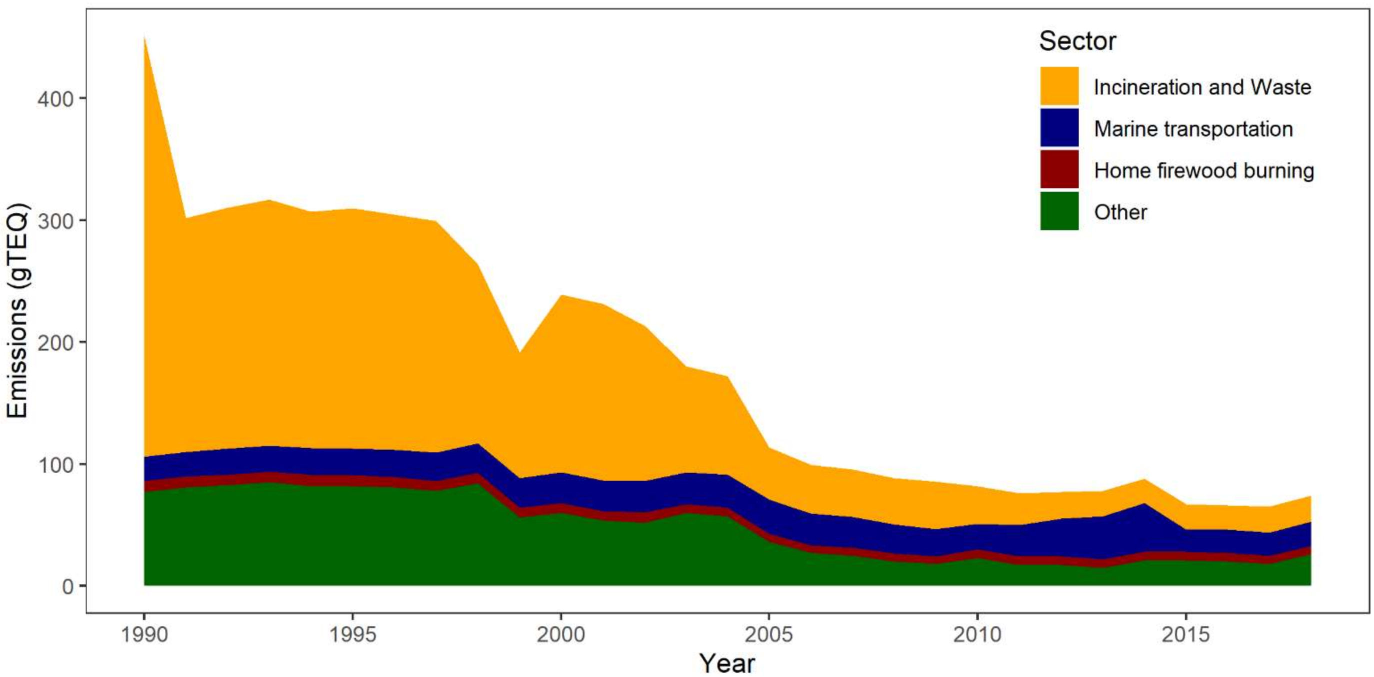

Figure 7. Canadian dioxin and furan emissions to air from 1990-2018. Source: Canada's Air Pollutant Emissions Inventory, 2020

In 2018, incineration and waste, marine transportation, and home firewood burning were the three sectors with the greatest dioxin and furan emissions to air (Figure 7). While the incineration and waste sector decreased emissions significantly since 1990 (from 346 g TEQ to 24 g TEQ in 2018, a 93% reduction), marine transportation emissions did not change (remaining at 20 g TEQ) and home firewood burning was responsible for 7 g TEQ in 2018, down slightly from 9 g TEQ in 1990.

It should be noted that the APEI does not report on some potentially important uncontrolled combustion sources of dioxin and furan emissions, including wildfires and landfill fires (Dwyer & Themelis, 2015).

5.1.3 Ambient Air Concentrations – National Air Pollution Surveillance (NAPS)

Figure 8 shows that the annual ambient air concentration of dioxins and furans dropped substantially in the 1990's, and concentration levels continued to decrease more slowly from the year 2000. More recent increases in wildfires in western Canada and the U.S. may contribute to ambient air concentrations of dioxins and furans and subsequent direct and indirect human exposure. The NAPS data record would not detect such changes as monitoring for dioxins and furans ceased in 2011.

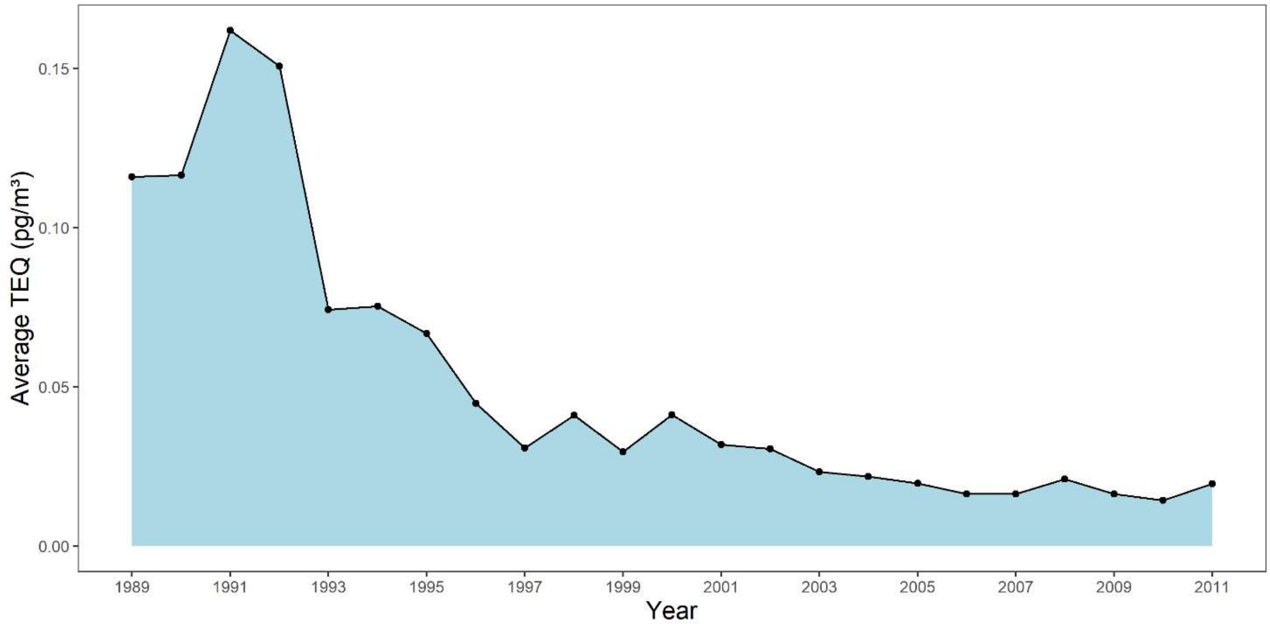

Figure 8. Average annual concentrations of dioxins and furans in ambient air across Canada from 1989 – 2011. Source: NAPS.

5.2 Dietary intake

5.2.1 Concentrations of dioxins and furans in certain foods

Previous findings looking at trends in dioxin and furan concentrations in Canadian foods have shown that dietary intakes fell about 50% from about 1 pg TEQ per day from the years 1985-1988 to less than 0.5 pg TEQ per day in 1999 (John Jake Ryan et al., 2013). A more recent time trend analysis of dioxins and furans, also expressed in TEQ concentrations, is presented below for certain foods of animal origin, which are the primary contributors of these chemicals in the diet of Canadians. Figures 9-12 were generated using data from the Canadian TDS (1992−2017), and targeted surveys conducted by Health Canada and the CFIA (2001−2013). Results presented for each food commodity represent composite samples (TDS data) or mean concentrations by survey year (Health Canada and CFIA targeted survey data).

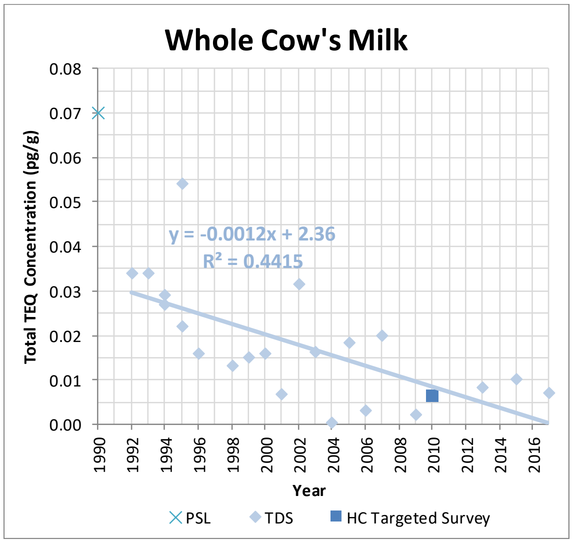

Figure 9. Whole Cow's Milk total TEQ

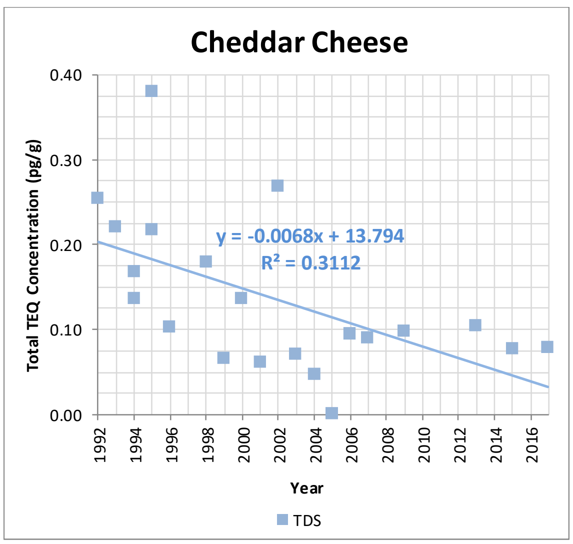

Figure 10. Cheddar Cheese total TEQ

The total TEQ concentration used in the PSL assessment was 0.07 pg/g in whole milk (Government of Canada, 1990). Due to their lipophilic nature, whole milk contains proportionally higher concentrations of dioxins and furans relative to lower-fat milks. The total TEQ concentration in whole milk was 10-fold lower in 2017 than in the original 1990 PSL assessment, and certain years of the TDS have had even lower concentrations (e.g., 2004, 2006, 2009). The data from the TDS as well as a targeted survey conducted by Health Canada (Health Canada's Food Directorate, personal communication) demonstrate a decrease in total TEQ concentrations in milk of other fat contents (i.e., skim, 1% and 2%), of between approximately 3- and 7-fold between 1992 and 2017 (data not shown).

The 1990 PSL assessment did not include data specifically for cheese, as data measured in milk fat were applied to all dairy products in that assessment (Government of Canada, 1990). Hard cheese, like cheddar, contains proportionally higher concentrations of dioxins and furans than lower-fat cheese (e.g., cottage cheese). Canadian data for cheddar cheese demonstrate a decrease in total TEQ concentrations of approximately 3-fold between 1992 and 2017. Processed and cottage cheeses exhibit a similar decreasing trend in total TEQ concentrations (data not shown).

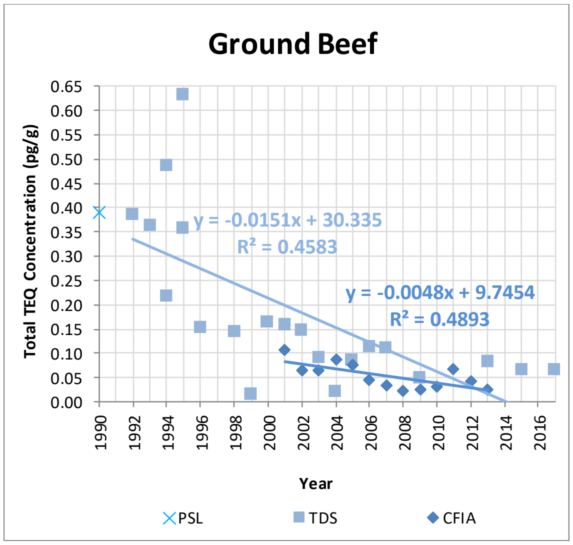

Figure 11. Ground Beef total TEQ

The 1990 PSL assessment reported a total TEQ concentration of 0.39 pg/g in beef (two samples of ground meat, one of organ meat, and five of steak). Ground beef is the most commonly consumed form of beef in Canada, according to the Canadian Community Health Survey (CCHS 2015). Dioxins and furans occur primarily in the fat, thus when only data for beef fat were available (CFIA data), they were converted to represent ground beef using fat content data from the Canadian Nutrient File (2015). The data in Figure 11 demonstrate that total TEQ concentrations in ground beef in 2017 are between approximately 6- (TDS data) and 16-fold (CFIA data) lower than the concentration employed in the 1990 PSL assessment.

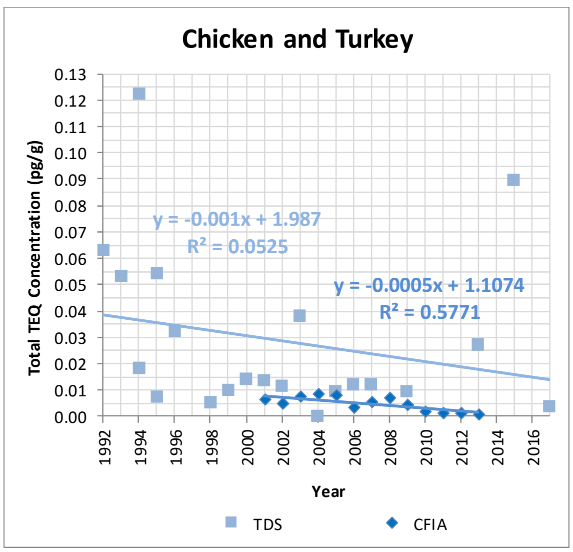

Figure 12. Ground Poultry (Chicken and Turkey) total TEQ

The 1990 PSL assessment assumed a total TEQ concentration of 0.56 pg/g in poultry based on five samples (data not shown). The poultry composite from the TDS is equal parts whole chicken and turkey, cooked, trimmed and ground. Dioxins and furans occur primarily in the fat, thus when only data on chicken fat were available (CFIA data), they were converted to represent ground chicken using fat content data from the Canadian Nutrient File (2015). Apart from one outlier (0.09 pg/g in the 2015 TDS), the TDS data demonstrate a decrease in total TEQ concentrations; those in 2017 are approximately 17-fold lower than those in 1992.

5.3 Biomonitoring

5.3.1 Concentration in Breastmilk

Data from several surveys (John Jake Ryan & Rawn, 2014; Rawn et al., 2017) indicate that concentrations of dioxin and furan congeners in Canadian human milk have decreased between 1986 and 2011 (Figure 13). For surveys that spanned multiple years, the data was plotted at the midpoint (i.e., MIREC study occurred from 2008-2011, so the corresponding data point was plotted between the years 2009 and 2010).

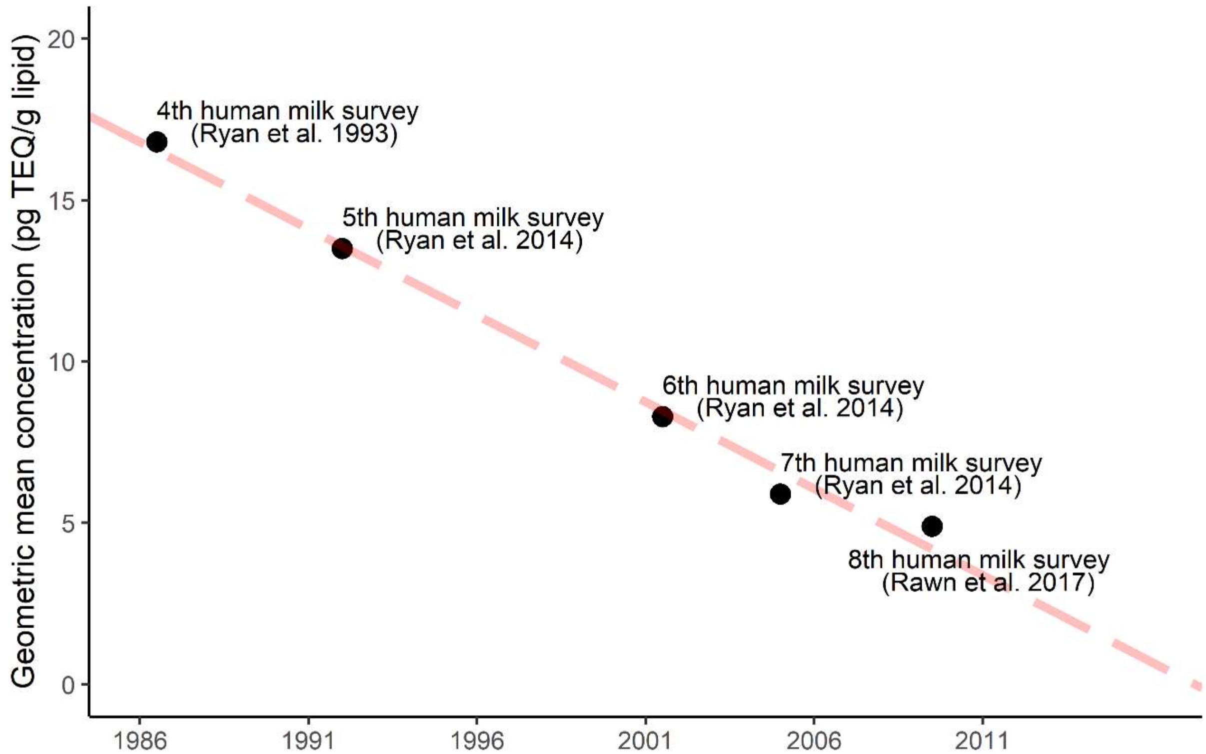

Figure 13. Geometric mean concentrations of dioxins and furans in Canadian human milk. Concentrations were calculated using WHO TEQ 2005. The line of best fit is shown in red.

The safe level for dioxins and furans in breast milk has been previously calculated at 0.2 pg/g milk lipid based on the lower limit of the tolerable daily intake set by the WHO at 1-4 pg/kg bodyweight/day (van den Berg et al., 2017). Average concentrations of dioxins and furans in the most recent breast milk measurements from the 2008-2011 MIREC study (geometric mean of approximately 5 ng TEQ / kg milk lipid) were still above the safe level. Despite this, the benefits of breast-feeding are still considered to outweigh the potential harmful effects of dioxins and furans at this level of exposure (Abraham, 2017).

5.3.2 Concentration in Blood – National Biomonitoring Program

Figure 14 shows the results for dioxins and furans in pooled serum data of the 1st, 3rd, 4th, and 5th CHMS cycles (2007-2009, 2012-2013, 2014-2015, and 2016-2017 respectively). Biomonitoring data indicate that concentrations of dioxins and furans have remained stable since 2007 in the Canadian population. Concentrations are generally higher in the older age groups compared to the younger age groups, likely reflecting bioaccumulation of these substances. The biomonitoring equivalents (15 ng TEQ/kg lipid for 12-19 year olds and 21 ng TEQ/kg lipid for those ≥20 years) are an estimate of the maximum concentration without increased risk of adverse health effects, and are based on the United States Environmental Protection Agency (US EPA) reference dose of $7x10^{-10}$ mg/kg bodyweight/day set in 2012 (US EPA IRIS, 2012; Aylward et al., 2013). Average dioxin and furan concentrations across all cycles are below the biomonitoring equivalents.

Between 2007 and 2015, the highest concentrations of dioxin-like chemicals measured in a small proportion of Canadians were above the biomonitoring equivalents for certain age groups indicating potential concerns for these individuals. More recently, as of 2016-2017, even the highest reported concentrations of dioxin-like chemicals were below the relevant guideline values.

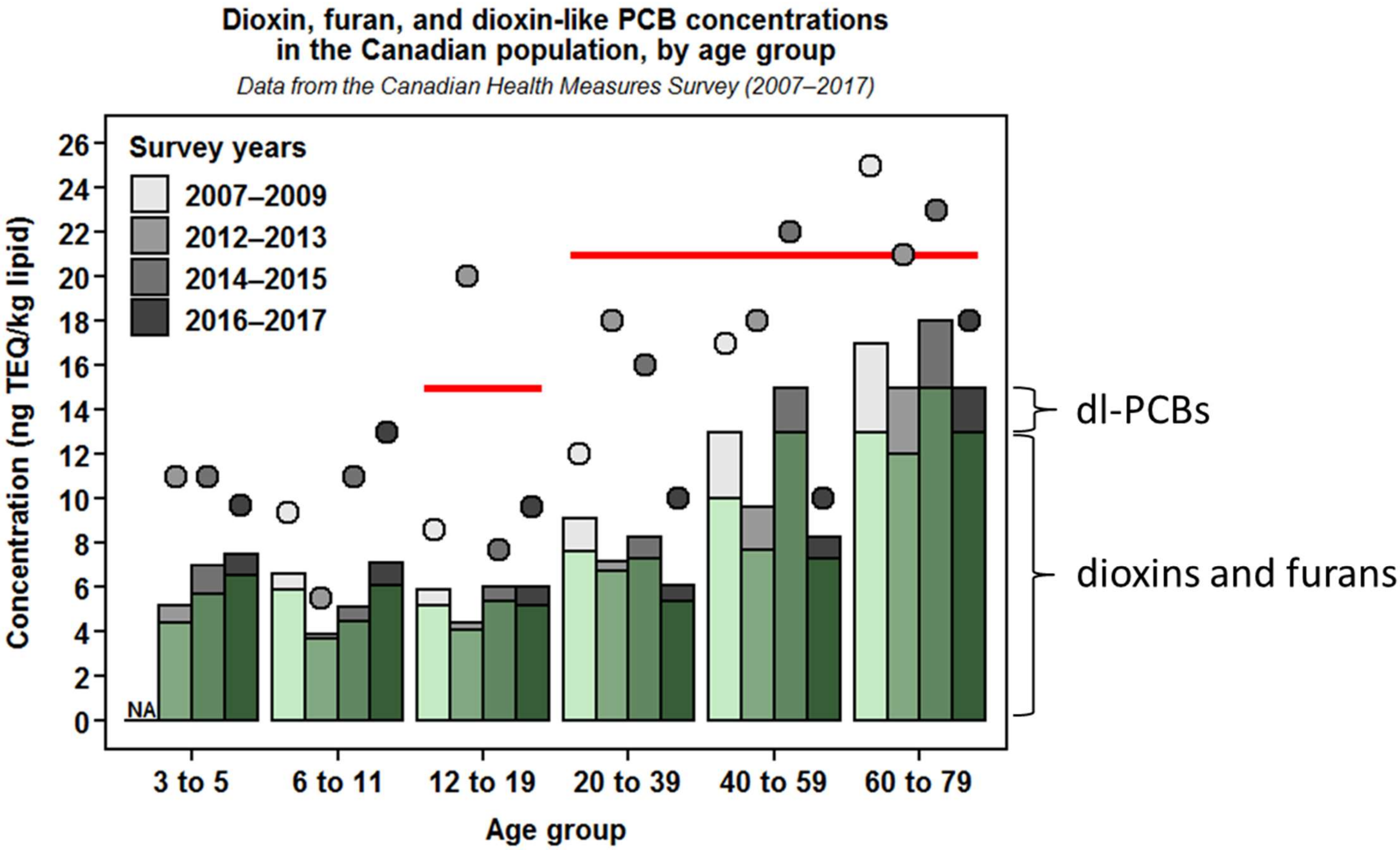

Figure 14. Dioxin, furan, and dl-PCB concentrations in blood serum in the Canadian population from the CHMS cycle 1 (2007-2009), cycle 3 (2012-2013), cycle 4 (2014-2015), and cycle 5 (2016-2017) by age group. Average (bar) and maximum (circle) concentrations of the Canadian population were calculated using WHO TEQ 2005. Concentrations were not available for children aged 3 to 5 in 2007-2009. The portion of average concentrations represented by dioxins and furans (but not dl-PCBs) is represented by green shading. The biomonitoring equivalent (15 ng TEQ/kg lipid for 12 to 19 year olds and 21 ng TEQ/kg lipid for 20 to 79 year olds) that correspond to the US EPA reference dose ($7x10^{-10}$ mg/kg bodyweight/day) are represented by red lines for comparison.

6. Performance Measurement Evaluation

Risk management actions taken on dioxins and furans in Canada seem to have been effective in reducing exposures to dioxins and furans across many mediums. Since the implementation of risk management strategies and tools came into effect, there has been a reduction in:

1. Levels of dioxins and furans emitted to, and measured in, outdoor air;
2. Concentrations in foods of animal origin and, as a result, dietary exposure to, dioxins and furans; and
3. Concentrations of dioxins and furans measured in human milk.

It is recognized that generally, a lag between the implementation of a risk management action and a response in the levels of exposures is expected, as it takes time for industries to adapt to new regulations and standards. For dioxins and furans, this lag may be more exaggerated due to their long half-lives, even when risk management actions are working effectively, reductions in the concentrations of dioxins and furans measured in the environment and in living organisms may only decrease gradually.

6.1 Environment

These compounds are found in air, water, and soil. Due to their chemical persistence and presence in the environment, dioxins and furans can also enter the food web. This means that any reductions in emissions to the environment would also be expected to eventually result in a decrease in Canadians' exposure to dioxins and furans.

The NPRI data show a clear decreasing trend in overall reported releases from the year 2000 to 2017 (Figure 2). The most dramatic drop in emissions occurred from 2004-2006, a period following the implementation of seven risk management actions from 2001-2003. When emissions were looked at by sector (Figure 3), all sectors showed decreases in emissions following the sector-specific risk management action. When looking at NPRI reported releases by province (Figure 4), Newfoundland and Labrador and Ontario were the two provinces with the greatest emissions and correspondingly saw the largest decreases. For Newfoundland and Labrador, there was a clear relationship with the CWS for Conical Waste Incineration, introduced in 2003 to phase out the operation of conical waste incinerators in this province. From 2000-2014, releases of dioxins and furans from waste incineration activities in Newfoundland and Labrador (which made up close to 100% of the province's dioxin and furan emissions) dropped from 53 g TEQ to 0.3 g TEQ, a reduction by over 99% (Figure 5). Reductions in Ontario seemed to be driven by reductions in the metal production and electricity sectors (Figure 6).

APEI data (Figure 7) shows that emissions to air by the evaluated sectors went down by 85% from 1990 to 2017, even when some non-industrial sources are considered. The three biggest reported sectors causing dioxin and furan emissions to air in 2017 were incineration and waste, marine transportation, and home firewood burning. The waste incineration sector showed a considerable decrease in emissions since 1990, with a large drop between 2004 and 2005 (81 g TEQ to 43 g TEQ, a 47% reduction), corresponding to the CWS for Waste Incineration, and the CWS for Conical Waste Combustion of Municipal Waste, which were developed for this sector and implemented in 2001 and 2003, respectively. Emissions from marine transportation and home firewood burning on the other hand have remained relatively stable.

NAPS data (Figure 8) reflect the fact that the reduced emissions that were reported by NPRI and estimated by APEI data sources resulted in lower amounts of measured dioxins and furans in ambient air between 1989 and 2011.

6.2 Dietary intake

As expected, based on the decreasing concentrations of total dioxin and furan TEQs in various foods observed since the 1990s (Figure 9–Figure 12), Canadians' total dietary exposure to dioxins and furans has also notably decreased since that time. The 1990 PSL assessment reported lower and upper bound mean dietary exposures to dioxins and furans in adult Canadians 17–70 years of age of 0.49 and 2.0 pg TEQ/kg bw per day, respectively. Estimates of mean dietary exposure to dioxins and furans in Canadians generated by Health Canada in 2019 ranged from 0.11 to 0.16 pg TEQ/kg bw per day depending on age and sex. The 95th percentile exposure estimates ranged from 0.37 to 0.52 pg TEQ/kg bw per day (Health Canada's Food Directorate, personal communication). These most recent dietary intakes are well below the tolerable daily intake value of 2.3 pg TEQ/kg bw per day, which is based on the 70 pg TEQ/kg bw tolerable monthly intake derived by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) (Joint FAO/WHO Expert Committee on Food Additives (JECFA), 2002). The safe limit of total daily intake of dioxins and furans recommended by the European Food Safety Authority (EFSA) was recently updated to 0.25 pg TEQ /kg bw per day (Knutsen et al., 2018). Although the recent EFSA value is approximately 9 times lower than the JECFA TDI of 2.3 pg TEQ /kg bw per day, considering the level of uncertainty and the number of assumptions applied to both the JECFA and EFSA Toxicity Reference Values (TRV), both are considered health protective.

6.3 Biomonitoring

Data obtained from several human milk surveys were available from 1985 to 2011, and provide a means for evaluating the cumulative effects of risk management actions. The data shows a consistent decrease in the concentrations of dioxins and furans measured in human milk, and can be described by a linear trend suggesting a reduction of about 0.54 pg TEQ / g lipid per year, or about a 3% reduction per year from 1985 levels, for a total 79% reduction.

Levels of dioxins and furans in blood (Figure 14) were only available after the implementation of all the risk management actions, although biomonitoring from other jurisdictions like the US show that human serum levels of dioxins and furans may have decreased by more than 80% since the 1980s (Aylward & Hays, 2002; Centers for Disease Control and Prevention, 2017). Despite this, it is possible that risk management actions taken in the early 2000s impacted the levels in the general population even years later. Blood-level measurements taken from a representative sample of the Canadian population show that the average levels of dioxins and furans are stable for all age groups and are below the biomonitoring equivalent thresholds, indicating that concentrations are below the level of concern. Those highly exposed in some age groups had concentrations of dioxins, furans, and dioxin-like PCBs that were of concern in earlier years, although data from the most recent cycle of CHMS (2016-2017) indicated levels below the biomonitoring equivalent thresholds for these same groups.

6.4 Other Considerations

6.4.1 Future Sources of Exposures

While PCBs are no longer being manufactured, furans were often created as contaminants in the production process (World Health Organization, 2019). Therefore, the improper disposal of PCBs represents a potential future source of release of furans. The Stockholm Convention requires the elimination of the use of PCBs in equipment by the year 2025, subject to review by the Conference of the Parties, and also requires Parties to make determined efforts designed to lead to environmentally sound waste management of liquids containing PCBs and equipment contaminated with PCBs by the year 2028. Attention should be paid to the proper disposal of equipment containing PCBs in order to ensure that Canadians continue to be protected from the effects of dioxin and furan exposure (UN Environment, 2017).

Climate change may trigger possible re-mobilization of dioxins and furans through intensified melting of permafrost (Bogdal et al., 2009). However, studies have shown that the rate of release is expected to be less than decreases from gradual degradation of dioxins and furans in the environment, and may not represent a notable source of future exposures (AMAP, 2016). Increased frequency of wildfires due to climate change may also increase the release of dioxins from burning of biomass and other materials such as plastics (Zhang et al., 2017).

New dioxin and furan contamination issues may arise in the food web as the use of industry by-products in livestock feeds increases and as novel sources and methods of processing feeds are developed. For example, hydrogenation of palm oil refining by-products (e.g., palm fatty acid distillates) can result in the transformation of dioxin congeners with lower TEFs to those with higher TEFs, therefore, increasing the total TEQ concentration in the hydrogenated product (Taverne-Veldhuizen et al., 2020). Use of certain copper recovery methods can result in dioxin and furan contamination in copper-based feed ingredients (Wang et al., 2014). Furthermore, novel sources of mined feed ingredients such as minerals, anticaking clays, and diatomaceous earth may disturb geogenic sources of dioxins (Codex Alimentarius Commission, 2006; Malisch & Kotz, 2014). Therefore, continued monitoring of these types of feed ingredients is important for limiting dietary exposure.

6.4.2 Vulnerable Populations

It was reported in the 2015 Arctic Monitoring and Assessment Programme (AMAP) Human Health Assessment that concentrations of POPs were elevated in the arctic with respect to other parts of Canada. Inuit communities in Nunavik and Nunavut in particular are highly impacted, likely due to higher consumption of marine mammals that contain dioxins and furans (Brown et al., 2018), and as a result of long range transport that leads to accumulation of dioxins and furans in northern regions as well (Hung et al., 2016). In certain areas of the Arctic, levels of POPs in blood may be 3-11 times higher than that of the general population (Arctic Monitoring and Assessment Programme (AMAP), 2015). There may also be higher rates of waste incineration in northern regions due to the constraints imposed by permafrost on creating landfills, which could also result in increased exposures to dioxins and furans. Other targeted programs such as the First Nations Food, Nutrition, and Environment Study have provided data for Indigenous populations in Southern Canada.

7. Conclusions

The Government of Canada's actions have directly resulted in reductions of dioxins and furans released into the environment, and their presence in the diet of Canadians. Biomonitoring results show that the risk management actions have also resulted in decreases in levels of dioxins and furans in Canadians as measured in breast milk. As expected, more recent measurements of these compounds in blood seem to be more stable.

Ongoing surveillance of releases of dioxins and furans in the environment and monitoring of levels in foods will allow the Government of Canada to identify potential new sources of dioxin and furan exposures. Biomonitoring will assist in determining whether exposures continue to trend downward in the general population and in Northern Indigenous populations.

A future performance measurement evaluation of these substances, as well as a health burden analysis, will help ensure that the Government of Canada continues to make progress in helping to protect the health of Canadians from the effects of dioxins and furans.

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