

Report

A Report of Pollutant Releases of Potential Radiological Concern from Major NORM Industries in Canada

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Activities involved with naturally occurring radioactive material (NORM) cover broad industrial sectors with very diverse characteristics. The main contributors to the NORM releases are mining and mineral processing industries. Releases from industries involving NORM are often produced in large amounts, but not well characterised radiologically; as a result, data are lacking to characterise public and worker exposures. The National Pollutant Release Inventory (NPRI) contains a total of 323 pollutants released to air, water and land from all industries in Canada. However, all major radionuclides from uranium and thorium series are not in the reporting list of NPRI. Given this constraint, this report advances our understanding of releases from NORM industries by describing the nature and magnitude of releases for pollutant substances reported in NPRI that are known to have naturally occurring radioactive isotopes other than in uranium and thorium series, and total particulate matters with great potential containing radionuclides from uranium and thorium series. The results indicate that NORM industries are responsible for almost all of the releases to air for the pollutant substances reviewed here: 100% for thallium and its compounds, 97% for lead and its compounds, 95% for cadmium and its compounds, 91% for selenium and its compounds, and 86% for total particulate matter ($< 100 \mu\text{m}$).

Key words: NORM, releases, pollution

1. Introduction

Natural radionuclides are present in the natural environment since the formation of the Earth. All minerals and natural raw materials contain the so-called 'primordial' radionuclides ^{238}U , ^{235}U and ^{232}Th and their decay progeny, as well as ^{40}K . Earth materials also contain other radionuclides of natural origin, often in trace amounts. The term of naturally occurring radioactive material (NORM) refers to radioactive material

containing no significant amounts of radionuclides other than naturally occurring radionuclides¹⁾, and covers all radionuclides of natural origin, primordial radionuclides and others in trace amounts. In the majority of situations, the concentrations of NORM are not sufficiently elevated to pose a radiological hazard and the material is not treated as being radioactive for purposes of radiological protection.

In most natural substances, the concentrations of radionuclides in NORM are low. However, higher concentrations may arise as the result of human activities. For example, at the extraction stage of Earth materials, naturally occurring radionuclides can become concentrated in primary raw materials, the extracted products, the generated residues and the waste

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Table 1. NAICS codes for industries involving NORM considered in this study.

NAICS	Industry	NAICS	Industry
211110	Oil and gas extraction (except oil sands)	324110	Petroleum refineries
211141	In-situ oil sands extraction	324121	Asphalt paving mixture and block manufacturing
211142	Mined oil sands extraction	324122	Asphalt shingle and coating material manufacturing
212114	Bituminous coal mining	324190	Other petroleum and coal product manufacturing
212115	Subbituminous coal mining	327120	Clay building material and refractory manufacturing
212116	Lignite coal mining	327214	Glass manufacturing
212210	Iron ore mining	327310	Cement manufacturing
212220	Gold and silver ore mining	327320	Ready-mix concrete manufacturing
212231	Lead-zinc ore mining	327330	Concrete pipe, brick and block manufacturing
212232	Nickel-copper ore mining	327390	Other concrete product manufacturing
212233	Copper-zinc ore mining	327410	Lime manufacturing
212291	Uranium ore mining	327420	Gypsum product manufacturing
212299	All other metal ore mining	327910	Abrasive product manufacturing
212314	Granite mining and quarrying	327990	All other non-metallic mineral product manufacturing
212315	Limestone mining and quarrying	331110	Iron and steel mills and ferro-alloy manufacturing
212316	Marble mining and quarrying	331210	Iron and steel pipes and tubes manufacturing from purchased steel
212317	Sandstone mining and quarrying	331221	Cold-rolled steel shape manufacturing
212323	Sand and gravel mining and quarrying	331222	Steel wire drawing
212326	Shale, clay and refractory mineral mining and quarrying	331313	Primary production of alumina and aluminum
212392	Diamond mining	331317	Aluminum rolling, drawing, extruding and alloying
212393	Salt mining	331410	Non-ferrous metal (except aluminum) smelting and refining
212395	Gypsum mining	331420	Copper rolling, drawing, extruding and alloying
212396	Potash mining	331490	Non-ferrous metal (except copper and aluminum) rolling, drawing, extruding and alloying
212398	All other non-metallic mineral mining and quarrying	331511	Iron foundries
221112	Fossil-fuel electric power generation	331514	Steel foundries
221113	Nuclear electric power generation	331523	Non-ferrous metal die-casting foundries
221310	Water supply and irrigation systems	331529	Non-ferrous metal foundries (except die-casting)

produced^{2,6}). The processing of raw materials by many resource-based industries may increase the concentration of radioactive substances in those materials, to levels at which special precautions are needed for handling, storing, transporting, and disposal of material, by-products, end-products or process equipment.

Exposures resulting from industrial activities involving NORM are controllable⁶). For public exposure, the approach is to control discharges and wastes, if necessary, after radiological characterization of the situation. Therefore, it is of public interest to know the nature and magnitude of the releases from various industrial activities involving NORM. However, this type of data is scarce in Canada. To fill the data gap, this study reviews and summarises detailed information on the releases from major industries involving NORM in Canada.

2. Methods and materials

Based on the Canadian Guidelines for the Management of NORM⁷), the following industries are considered as having the potential to hold, produce, and/or release NORM in amounts sufficient to cause significant radiation doses to workers and radiological burdens to the environment. They are mineral extraction and processing (NORM may be released or concentrated in a process stream during the processing of ore), oil and gas production (NORM

may be found in the liquids and gases from hydrocarbon-bearing geological formations), thermal-electric production (mineral ashes left from combustion may concentrate small amounts of NORM present naturally in coal) and water treatment facilities (fresh or waste water is treated through sorptive media or ion-exchange resins to remove minerals and other impurities from the water being treated). Industries involving NORM considered in this study are given in Table 1. Classification of industries is given by the North American Industry Classification System (NAICS)⁸).

Releases from all industries in Canada are required to be reported in the National Pollutant Release Inventory (NPRI)⁹). The NPRI is Canada's public inventory of pollutant releases (to air, water and land), disposals and transfers for recycling. Facility-reported raw data are available online at Government of Canada's Open Data website. Annual data files (1993 to 2020) contain facility-reported data listed by facility and substance for a given year¹⁰).

The substances listed on the NPRI are organized into five parts, each having different reporting requirements for a total of 323 substances¹¹). Part 1A is referred to as "core substances", this group makes up the majority of substances on the NPRI list and most have been on it since the start of the NPRI. Substances in Part 1B are referred to as "alternate threshold substances" and have

Table 2. Substances identified from NPRI-list which potentially contain naturally occurring radionuclides.

Substance	NPRI Part #	Reporting threshold
Cadmium (and its compounds)	Part 1B	5 kg MPO
Lead (and its compounds)	Part 1B	50 kg MPO
Selenium (and its compounds)	Part 1B	100 kg MPO
Thallium (and its compounds)	Part 1B	100 kg MPO
Thorium dioxide	Part 1A	10 tonnes MPO
Total Particulate Matter*	Part 4	20 tones release

* Filterable particulate matter, on a dry basis. Excludes condensable particulate matter. Particulate matter with a diameter less than 100 micrometres.

Note: MPO "Manufactured, processed or otherwise used" refers to the amount of the substance produced, prepared or used in any other way at a facility.

Table 3. Five-year (2015-2019) average annual total releases by substances in Canada.

Substance	Release to air		Release to water		Release to land	
	No. reporting facilities	Annual release (tonnes)	No. reporting facilities	Annual release (tonnes)	No. reporting facilities	Annual release (tonnes)
Cadmium (and its compounds)	316	6.325	166	2.610	11	0.1494
Lead (and its compounds)	434	126.3	206	9.577	49	96.69
Selenium (and its compounds)	235	14.69	107	18.47	5.0	0.1016
Thallium (and its compounds)	34	0.4713	21	1.897	1.4	0.0175
Thorium dioxide	-	-	-	-	-	-
Total Particulate Matter	3287	392538	-	-	-	-

a lower reporting threshold than Part 1A substances. They may have significant environmental or human health impacts in small amounts. Substances in Part 2 are polycyclic aromatic hydrocarbons that may be used as commercial chemicals, incidentally manufactured in certain industrial processes, or contained in tailings. Substances in Part 3 are polychlorinated dibenzo-p-dioxins (dioxins), polychlorinated dibenzofurans (furans) and hexachlorobenzene that are released as by-products of industrial and combustion processes. Part 4 is for substances known as criteria air contaminants, commonly released from combustion sources that can cause or contribute to air issues such as smog and acid rain. Part 5 is for volatile organic compounds which are subject to additional reporting requirements.

For the need of radiation protection in workplaces involving minerals and raw materials, the International Atomic Energy Agency (IAEA) provided guidance on activity concentrations below which it is usually unnecessary to regulate³⁾:

- 1 Bq/g for uranium and thorium series radionuclides;
- 10 Bq/g for ⁴⁰K.

The IAEA also provided detailed list of materials released from industries involving NORM to be assessed for possible regulatory control³⁾. The radionuclide activity concentrations to be determined are

- Uranium series: ²³⁸U, ²²⁶Ra, ²¹⁰Pb and ²¹⁰Po;
- Thorium series: ²³²Th, ²²⁸Ra and ²²⁸Th.

Unfortunately, the NPRI does not collect any information

about the above listed key radionuclides from uranium and thorium series of radiological health concerns. Even though NPRI list of pollutant substances does not specifically contain radioactive substances and there is no list of substances that are considered most important in terms of NORM (such as a process stream contaminated with radium isotopes), trace amounts of naturally occurring radionuclides and their compounds can be present in some releases from industrial activities involving NORM, especially the large quantity of total particulate matter (< 100 µm) released to air that have high potential containing harmful radionuclides from uranium and thorium series³⁻⁶⁾. From the long list of substances, the following are identified which may contain naturally occurring radionuclides, as given in Table 2.

According to the convention of five-year periods for exposure evaluation implemented by the United Nations Scientific Committee on the Effects of Atomic Radiation Global Survey (survey.unscear.org), this study reviews detailed release data by substances that may be of radiological interest for the same period (2015-2019).

3. Results and discussion

From the NPRI website (<https://www.canada.ca/en/environment-climate-change/services/national-pollutant-release-inventory/tools-resources-data/exploredata.html>), facility-reported raw release data by substances were downloaded for five years (2015-2019). Sorted by the six-

Table 4. Summary of detailed release information for oil and gas industry in 2019.

NAICS	Substance Name (unit)	Release to	211110		211141		211142		2111	
			NRF	Release	NRF	Release	NRF	Release	Total NRF	Total release
Cadmium (and its compounds) (kg)	air		2	3.821	5	85.15	6	77.14	13	166.1
	water		1	0.007	-	-	4	1.289	5	1.296
	land		-	-	-	-	-	-	-	-
Lead (and its compounds) (kg)	air		1	1.901	-	-	7	176.6	8	178.5
	water		-	-	-	-	5	3.974	5	4.0
	land		-	-	-	-	1	0.008	1	0.008
Selenium (and its compounds) (kg)	air		2	4.251	-	-	4	143.5	6	147.8
	water		-	-	-	-	5	76.48	5	76.5
	land		-	-	-	-	2	0.023	2	0.023
Thallium (and its compounds) (kg)	air		-	-	-	-	1	0.000037	1	0.000
	water		-	-	-	-	1	0.948	1	0.948
	land		-	-	-	-	1	1.525	1	1.525
Total particulate matter (tonnes)	air		2263	4055	24	586	8	13084	2295	17725
Range of total particulate matter				(0, 458)		(1.7, 96)		(3.7, 8610)		

2111: Oil and gas extraction; 211110: Oil and gas extraction (except oil sands); 211141: In-situ oil sands extraction; 211142: Mined oil sands extraction

Table 5. Summary of detailed release information for coal mining (NAICS 2121) in 2019.

NAICS	Substance Name (unit)	Release to	212114		212115		212116		2121	
			NRF	Release	NRF	Release	NRF	Release	Total NRF	Total release
Cadmium (and its compounds) (kg)	air		8	2.950	-	-	-	-	8	2.950
	water		8	39.48	-	-	-	-	8	39.481
	land		-	-	-	-	-	-	-	-
Lead (and its compounds) (kg)	air		9	22.37	-	-	-	-	9	22.370
	water		8	19.82	-	-	-	-	8	19.820
	land		-	-	-	-	-	-	-	-
Selenium (and its compounds) (kg)	air		3	1.380	-	-	-	-	3	1.380
	water		2	1.67	-	-	-	-	2	1.670
	land		-	-	-	-	-	-	-	-
Thallium (and its compounds) (kg)	air		3	1.381	-	-	-	-	3	1.381
	water		2	1.665	-	-	-	-	2	1.665
	land		-	-	-	-	-	-	-	-
Total particulate matter (tonnes)	air		11	106470	5	6047	3	389	19	112906
Range of total particulate matter				(4, 39972)		(7, 5967)		(30, 308)		

212114: Bituminous coal mining; 212115: Subbituminous coal mining; 212116: Lignite coal mining.

digits NAICS code, the 5-year average total releases for the identified substances listed in Table 2 are summarised in Table 3. Releases to air include stack emissions, storage/handling, fugitive emissions, spills and others. Releases to water include direct discharge, spills, and leaks. Releases to land include spills, leaks and others. There was no report for releases of thorium dioxide from 2015 to 2019. Most of the identified substances were released to the air, dominated by total particulate matter (<100 µm) for which the chemical and radiological characteristics are unknown. Among the substances containing naturally occurring radionuclides, lead and its compounds were the most reported and released. A total of 689 facilities reported above threshold releases of lead and its compounds, 126 tonnes to the air, 97 tonnes to land and about 10 tonnes to water system.

Table 3 provides total annual releases by substances potentially containing naturally occurring radioactive

materials in Canada. At this time, information is not available to consider radioactive and non-radioactive materials separately. However, it is of interest to know the amounts of these substances released by major industries involving NORM. This detailed analysis was conducted for year 2019. The NPRI data file of 2019 contained a total of 57841 reporting entries from various industries in Canada. Even though there are reporting thresholds for various substances, a significant number of facilities reported data for releases below the reporting threshold values. The data file can be sorted by 4-digit and 6-digit NAICS codes as given in Table 1 and for selected substances individually. Results of the analyses for major industries involving NORM in Canada are summarised in the tables below.

Table 4 summarises detailed release information for oil and gas extraction industry where NRF stands for number of reporting facilities. For the four substances

Table 6. Summary of releases from metal mining industries (NAICS 2122) in 2019.

NAICS		212210		212220		212231		212232		212233		212291		212299		2122	Total release
Substance Name (unit)	Release to	NRF	Release	NRF	Release	NRF	Release	NRF	Release	NRF	Release	NRF	Release	NRF	Release	Total NRF	
Cadmium (and its compounds) (kg)	air	7	54.21	24	4.524	1	11.76	13	7.837	6	70.69	1	0.019	1	0.008	53	149.1
	water	4	6.57	24	13.03	1	0.062	9	8.219	9	60.02	3	0.0412	3	1.263	53	89.21
	land			1	17.94											1	17.94
Lead (and its compounds) (kg)	air	7	3081	27	458.4	2	3677.0	14	272.9	7	442.4	2	0.039	2	22.766	61	7954
	water	6	24.79	31	67.71	2	52.3	9	43.42	12	53.73	4	2.17	3	4.794	67	248.9
	land			2	2215					1	0.291					3	2215
Selenium (and its compounds) (kg)	air	4	241.3	14	10.25			16	144.9	7	149.1			1	0.192	42	545.7
	water	1	0.005	18	419.3			9	1499	10	2391	2	38.34	3	219.360	43	4568
	land			1	173.9					1	0.0005					2	173.9
Thallium (and its compounds) (kg)	air	2	183.7	11	3.655	1	0.0001	4	7.859	2	36.744			1	0.0269	21	231.9
	water	1	0	12	14.13	1	0.044	2	3	3	0.893	1	2.074			20	20.14
	land			1	24.72											1	24.72
Total particulate matter (tonnes)	air	11	12962	35	3799	2	102	15	856	9	17231	4	241	7	462	83	35653
Range of total particulate matter			(10.26, 9802)		(0.008, 2221)		(39.48, 62.95)		(0, 240.5)		(0.67, 9111)		(18.14, 140.3)		(1.23, 374.9)		

212210: Iron ore mining; 212220: Gold and silver ore mining; 212231: Lead-zinc ore mining; 212232: Nickel-copper ore mining; 212233: Copper-zinc ore mining; 212291: Uranium ore mining; 212299: All other metal ore mining.

known to potentially have naturally occurring radioactive isotopes, from the most to the least, the total amounts released to the environment in 2019 are 224.3 kg of selenium and its compounds, 182.5 kg of lead and its compounds, 167.4 kg of cadmium and its compounds, and 2.5 kg of thallium and its compounds. The majority of the substances are released to air during oil sands extraction.

Table 5 provides detailed release information for coal mining industry. The total amounts released to the environment in 2019 are 42 kg for cadmium, lead and their compounds, and 3 kg for selenium, thallium and their compounds. More substances are released to water than to air in bituminous coal mining. In subbituminous and lignite coal mining, there was only releases of total particulate matter (<100 µm). Even for the release of total particulate matter, bituminous coal mining dominates the release amount.

Table 6 summarises detailed release information for various metal mining. In metal mining, most releases to the environment are lead and its compounds with a total of 10,419 kg (dominated by releases to air from iron ore mining and lead-zinc ore mining), followed by selenium and its compounds of 5287 kg (dominated by releases to water from nickel-copper ore mining and copper-zinc ore mining).

Detailed release information from non-metal mining industries is provided in Table 7. The release is mainly lead and its compounds from diamond mining. All other non-metal mining has no or below-threshold releases to the environment except the total particulate matter. The release of total particulate matter is mainly from potash mining and limestone mining and quarrying.

Detailed release information from fossil-fuel electric

power generation is given in Table 8. Major releases are lead and its compounds, followed by selenium and its compounds, cadmium and its compounds and thallium and its compounds. There are large amounts of total particulate matter released from fossil-fuel electric power generation. For comparison purpose, Table 8 also includes reported release information from hydro-electric power generation and nuclear electric power generation, both of which produce only negligible quantities of particulate matter compared to fossil fuel electric power generation.

Releases from petroleum and coal product manufacturing were summarised in Table 9. Substances potentially containing naturally occurring radionuclides and their compounds were released from petroleum refineries. Other petroleum and coal product manufacturing activities only reported to release total particulate matter with no radiological characterization. About 84% of total particulate matter was released from petroleum refineries.

Table 10 summarises releases from non-metallic product manufacturing. Almost all releases except total particulate matter are from cement manufacturing (dominated by lead and its compounds). Cement and lime manufacturing released significant amounts of total particulate matter, as did many other non-metallic mineral product manufacturing.

For metal product manufacturing, major releases were from iron and steel mills and ferro-alloy manufacturing (NAICS 331110) and non-ferrous metal (except aluminum) smelting and refining (NAICS 331410), as shown in Table 11. Most substances released are lead and its compounds of 96.1 tonnes, followed by selenium and its compounds of 10.4 tonnes. A total of 13.9 tonnes of total particulate matter were released to air by metal product

Table 7. Summary of releases from non-metallic mineral mining industries (NAICS 2123) in 2019.

NAICS	212314		212315		212316		212317		212323		212326		
Substance Name (unit)	Release to	NRF	Release	NRF	Release	NRF	Release	NRF	Release	NRF	Release	NRF	Release
Cadmium (and its compounds) (kg)	air											1	0.011
	water												
	land												
Lead (and its compounds) (kg)	air						1	0.031				1	0.405
	water						1	1.411					
	land												
Selenium (and its compounds) (kg)	air												
	water												
	land												
Thallium (and its compounds) (kg)	air												
	water												
	land												
Total particulate matter (tonnes)	air	5	86.75	34.00	2163	1	16.97			32	740	2	79.0
Range of total particulate matter			(1.858, 30.93)		(1.698, 368.9)						(2.479, 81.78)		(7.748, 71.203)

Table 7. continue

NAICS	212392		212393		212395		212396		212398		2123		
Substance Name (unit)	Release to	NRF	Release	NRF	Release	NRF	Release	NRF	Release	NRF	Release	Total NRF	Total release
Cadmium (and its compounds) (kg)	air	4	3.264									5	3.274
	water	2	0.0361									2	0.036
	land												
Lead (and its compounds) (kg)	air	4	46.14									6	46.57
	water	2	0.0817									3	1.493
	land												
Selenium (and its compounds) (kg)	air	4	0.7591									4	0.759
	water	2	1.569									2	1.569
	land												
Thallium (and its compounds) (kg)	air	1	0.0013									1	0.001
	water												
	land												
Total particulate matter (tonnes)	air	6	691	5	427.2	3.0	25.4	13.0	6422	6	74.5	107	10726
Range of total particulate matter			(0.74, 392.2)		(15.03, 202.1)		(3.859, 15.67)		(2.593, 1073)		(0.795, 24.17)		

212314: Granite mining and quarrying; 212315: Limestone mining and quarrying; 212316: Marble mining and quarrying; 212317: Sandstone mining and quarrying; 212323: Sand and gravel mining and quarrying; 212326: Shale, clay and refractory mineral mining and quarrying; 212392: Diamond mining; 212393: Salt mining; 212395: Gypsum mining; 212396: Potash mining; 212398: All other non-metallic mineral mining and quarrying.

manufacturing.

The above information is summarised in Table 12 by sectors of industries involving NORM. In order to know how much industries involving NORM contributed to the overall releases to the environment, total releases from all industries reported to the NPRI are also summarised in Table 12 under “All NAICS”. The last column of Table 12 calculates the percentage of releases from identified industries involving NORM to the total releases from all industries combined. The pathway where industries involving NORM play the biggest role is releases to air, where contributions (as a percentage of the total for all industries) are 100% for thallium and its compounds, 97% for lead and its compounds, 95% for cadmium and its compounds, 91% for selenium and its compounds, and 86% for total particulate matter (< 100 µm). Even though the

total particulate matter is not characterised radiologically, it contributes to air pollution.

4. Conclusions

Activities involved with naturally occurring radioactive material cover broad industrial sectors with diverse characteristics. Releases from industries involving NORM are often produced in large amounts, but not well characterised radiologically. The review describes the nature and magnitude of releases in Canada with detailed analysis for 2019. From a total of 323 substances required for reporting to the National Pollutant Release Inventory^{1D}, four substances were identified as potentially containing naturally occurring radionuclides in varying concentrations. In 2019, most of these substances were

Table 8. Summary of releases from electric power generation industries in 2019

NAICS	Substance Name (unit)	Release to	221111		221112		221113		2211	
			NRF	Release	NRF	Release	NRF	Release	Total NRF	Total release
Cadmium (and its compounds) (kg)	air	air			16	103.5			16	103.5
		water			6	1.732			6	1.732
		land								
Lead (and its compounds) (kg)	air	air			17	1370	1	8.8	18	1379
		water			8	11.02			8	11.02
		land					1	120.9	1	120.9
Selenium (and its compounds) (kg)	air	air			10	642.8			10	642.8
		water			5	15.59			5	15.59
		land								
Thallium (and its compounds) (kg)	air	air			6	26.05			6	26.05
		water			3	0.573			3	0.573
		land								
Total particulate matter (tonnes)	air	2	0.088	35	13237			37	13237	
Range of total particulate matter			(0.005, 0.083)		(0.3899, 5902)				(0.005, 5902)	

221111: Hydro-electric power generation; 221112: Fossil-fuel electric power generation; 221113: Nuclear electric power generation.

Table 9. Summary of releases from petroleum and coal product manufacturing (NAICS 3241) in 2019.

NAICS	Substance Name (unit)	Release to	324110		324121		324122		324190		3241	
			NRF	Release	NRF	Release	NRF	Release	NRF	Release	Total NRF	Total release
Cadmium (and its compounds) (kg)	air	air	12	68.75							12	68.75
		water	4	14.60							4	14.60
		land										
Lead (and its compounds) (kg)	air	air	10	241.2							10	241.2
		water	5	210.6							5	210.6
		land										
Selenium (and its compounds) (kg)	air	air	5	58.80							5	58.80
		water	3	79.99							3	79.99
		land	1	24.30							1	24.30
Thallium (and its compounds) (kg)	air	air										
		water										
		land										
Total particulate matter (tonnes)	air	15	3487	20	188.6	5	111.9	2	365.2	42	4153	
Range of total particulate matter			(0.89, 765.8)		(0.007, 73.34)		(2.81, 43.36)		(45.05, 320.2)		(0.007, 765.8)	

324110: Petroleum refineries; 324121: Asphalt paving mixture and block manufacturing; 324122: Asphalt shingle and coating material manufacturing; 324190: Other petroleum and coal product manufacturing.

Table 10. Summary of releases from non-metallic product manufacturing (NAICS 327) in 2019.

NAICS	Substance Name (unit)	Release to	327120		327214		327310		327320		327330		327390	
			NRF	Release	NRF	Release	NRF	Release	NRF	Release	NRF	Release	NRF	Release
Cadmium (and its compounds) (kg)	air	air					4	1.77						
		water												
		land												
Lead (and its compounds) (kg)	air	air					7	384.9						
		water												
		land												
Selenium (and its compounds) (kg)	air	air			2	0.022	7	65.76						
		water												
		land												
Thallium (and its compounds) (kg)	air	air					1	11.76						
		water												
		land												
Total particulate matter (tonnes)	air	1	38.90	3	163.7	15	2648	18	13.53	2	1.35	1	0.0196	
Range of total particulate matter				(38.05, 64.80)		(33.0, 456.2)		(0.023, 4.147)		(0.063, 1.284)				

Table 10. Continue

NAICS Substance Name (unit)	Release to	327410		327420		327910		327990		327		
		NRF	Release	NRF	Release	NRF	Release	NRF	Release	Total NRF	Total release	
Cadmium (and its compounds) (kg)	air										4	1766
	water											
	land											
Lead (and its compounds) (kg)	air	1	4.21								8	389.1
	water											
	land											
Selenium (and its compounds) (kg)	air								1	0.017	10	65.80
	water											
	land											
Thallium (and its compounds) (kg)	air										1	11.76
	water											
	land											
Total particulate matter (tonnes)	air	9	1819	5	71.58	2	44.34	11	337.5	67	5138	
Range of total particulate matter		(30.32, 504.3)		(0.023, 44.69)		(3.44, 40.9)		(4.42, 83.23)		(0.023, 504.3)		

327120: Clay building material and refractory manufacturing; 327214: Glass manufacturing; 327310: Cement manufacturing; 327320: Ready-mix concrete manufacturing; 327330: Concrete pipe, brick and block manufacturing; 327390: Other concrete product manufacturing; 327410: Lime manufacturing; 327420: Gypsum product manufacturing; 327910: Abrasive product manufacturing; 327990: All other non-metallic mineral product manufacturing.

Table 11. Summary of releases from metal product manufacturing (NAICS 331) in 2019.

NAICS Substance Name (unit)	Release to	331110		331210		331221		331222		331313		331317		331410	
		NRF	Release	NRF	Release	NRF	Release	NRF	Release	NRF	Release	NRF	Release	NRF	Release
Cadmium (and its compounds) (kg)	air	11	168.6											11	3926
	water	5	35.21											7	311.9
	land	1	0.0033												
Lead (and its compounds) (kg)	air	13	4880			2	0.182	3	359.6			2	1.116	12	85605
	water	9	809.1					3	179.5					8	1137
	land	1	0.3806												
Selenium (and its compounds) (kg)	air	6	36.49											7	8058
	water	3	13.55											5	2287
	land														
Thallium (and its compounds) (kg)	air	1	0.7368											3	338.8
	water													2	1150.8
	land	1	0.0072												
Total particulate matter (tonnes)	air	14	6177	4	15.67			2	77.47	13	5257	3	137.1	11	2003
Range of total particulate matter		(24.28, 1815)		(0.2391, 10.31)				(21.9, 55.57)		(3.301, 2055)		(9.8, 76.19)		(9.552, 1094)	

Table 11 Continue

NAICS Substance Name (unit)	Release to	331420		331490		331511		331514		331523		331529		331		
		NRF	Release	NRF	Release	NRF	Release	NRF	Release	NRF	Release	NRF	Release	Total NRF	Total release	
Cadmium (and its compounds) (kg)	air			2	0.163	2	0.973	2	365.1						28	4461
	water														12	347.1
	land														1	0.003
Lead (and its compounds) (kg)	air			4	85.60	6	121.3	3	1213	1	3.84	7	1697	53	93967	
	water											1	15.1	21	2141	
	land											1	0.5	2	0.881	
Selenium (and its compounds) (kg)	air	1	0.441	1	0			1	0.159			1	2	17	8097	
	water			1	10.9									9	2312	
	land															
Thallium (and its compounds) (kg)	air													4	339.5	
	water													2	1151	
	land													1	0.007	
Total particulate matter (tonnes)	air					4	99.5	4	84.24	1	0.021	1	15	57	13866	
Range of total particulate matter						(0.928, 64.97)		(10.87, 25.91)						(0.24, 2055)		

331110: Iron and steel mills and ferro-alloy manufacturing; 331210: Iron and steel pipes and tubes manufacturing from purchased steel; 331221: Cold-rolled steel shape manufacturing; 331222: Steel wire drawing; 331313: Primary production of alumina and aluminum; 331317: Aluminum rolling, drawing, extruding and alloying; 331410: Non-ferrous metal (except aluminum) smelting and refining; 331420: Copper rolling, drawing, extruding and alloying; 331490: Non-ferrous metal (except copper and aluminum) rolling, drawing, extruding and alloying; 331511: Iron foundries; 331514: Steel foundries; 331523: Non-ferrous metal die-casting foundries; 331529: Non-ferrous metal foundries (except die-casting).

Table 12. Summary of releases from sectors involving NORM in comparison with releases from all industries reported to NPRI in 2019.

NAICS		All NAICS		2111		2121		2122		2123		2211	
Substance Name (unit)	Release to	NRF	Release	NRF	Release	NRF	Release	NRF	Release	NRF	Release	NRF	Release
Cadmium (and its compounds) (kg)	air	263	5216	13	166.1	8	2.950	53	149.1	5	3.274	16	103.5
	water	170	2936	5	1.296	8	39.48	53	89.21	2	0.036	6	1.732
	land	8	108.4					1	17.94				
Lead (and its compounds) (kg)	air	375	107265	8	178.5	9	22.37	61	7954	6	46.57	18	1379
	water	212	9579	5	3.974	8	19.82	67	248.9	3	1.493	8	11.02
	land	55	120374	1	0.008			3	2215			1	120.9
Selenium (and its compounds) (kg)	air	196	10500	6	147.8	3	1.380	42	545.7	4	0.759	10	642.8
	water	111	18047	5	76.48	2	1.670	43	4568	2	1.569	5	15.59
	land	7	198.2	2	0.023			2	173.9				
Thallium (and its compounds) (kg)	air	36	610.6	1	0.000	3	1.381	21	231.9	1	0.001	6	26.05
	water	30	1174	1	0.948	2	1.665	20	20.14			3	0.573
	land	3	26.26	1	1.525			1	24.72				
Total particulate matter (tonnes)	air	3388	249414	2295	17725	19	112906	83	35653	107	10726	37	13237

Table 12. Continue.

NAICS		3241		327		331		All NORMs		%
Substance Name (unit)	Release to	NRF	Release	NRF	Release	NRF	Release	NRF	Release	NORMs/All
Cadmium (and its compounds) (kg)	air	12	68.75	4	1.766	28	4461	139	4956	95%
	water	4	14.60			12	347.1	90	493.5	17%
	land					1	0.003	2	17.94	17%
Lead (and its compounds) (kg)	air	10	241.2	8	389.1	53	93967	173	104178	97%
	water	5	210.6			21	2141	117	2636	28%
	land					2	0.881	7	2337	2%
Selenium (and its compounds) (kg)	air	5	58.80	10	65.80	17	8097	97	9560	91%
	water	3	79.99			9	2312	69	7054	39%
	land	1	24.30					5	198.2	100%
Thallium (and its compounds) (kg)	air			1	11.76	4	339.5	37	610.6	100%
	water					2	1151	28	1174	100%
	land					1	0.007	3	26.26	100%
Total particulate matter (tonnes)	air	42	4153	67	5138	57	13866	2707	213404	86%

released to air: 104 tonnes of lead and its compounds, 9.56 tonnes of selenium and its compounds, 4.96 tonnes of cadmium and its compounds, and 0.61 tonnes of thallium and its compounds. While total particulate matter (< 100 µm) is not characterised radiologically, it clearly contributes to air pollution and may contain trace amounts of radionuclides of natural origin, with industries involving NORM contributing 86% of the total releases from all industries combined. Even though this review cannot draw conclusions about the radiological aspects of the releases described here, it is the first step towards better characterizing public radiation exposure to releases potentially containing naturally occurring radioactive material from industries involving NORM in Canada.

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