

**MINAMATA
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ON MERCURY**

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**Conference of the Parties to the
Minamata Convention on Mercury
Fourth meeting**

Online, 1–5 November 2021*

Item 4 (d) of the provisional agenda**

**Matters for consideration or action by the Conference of
the Parties: mercury waste: consideration of the relevant
thresholds****Report on the intersessional work on mercury waste: technical
annexes****Note by the secretariat**

As is mentioned in the note by the secretariat containing the report on the intersessional work on mercury waste (UNEP/MC/COP.4/8), the technical annexes to the report of the group of technical experts established pursuant to decision MC-2/2 are set out as annexes to the present note. Annex I presents the technical analysis of options in establishing thresholds for mercury waste falling under subparagraph 2 (c) of article 11, i.e. waste contaminated with mercury or mercury compounds. Annex II presents a description of the technical calculation of a proposed threshold for tailings from industrial-scale non-ferrous metal mining other than primary mercury mining, which is to be used after the tier-1 threshold based on total mercury concentration and is based on leach testing. The annexes have not been formally edited.

* The resumed fourth meeting of the Conference of the Parties to the Minamata Convention on Mercury is to convene in person in Bali, Indonesia, and is tentatively scheduled for the first quarter of 2022.

** UNEP/MC/COP.4/1.

Annex I

Technical analysis of threshold options for waste contaminated with mercury or mercury compounds*

This document presents a technical analysis of threshold options included in Document UNEP/MC/COP.3/7 - (a) total concentration of mercury in a waste, (b) measures of the release potential of mercury in a waste, and (c) a qualitative determination (i.e., a listing approach).

From this analysis, it has been concluded that a total concentration threshold is currently the most appropriate way to identify Category C waste subject to the Minamata Convention. Listing approach is not feasible for establishing thresholds for a wide variety of Category C waste. When compared to the leaching procedure, the total concentration approach has the following advantages:

1. Category C wastes are managed in a large variety of ways, and not only land disposed, as illustrated by the USA coal combustion waste data below. Leaching procedures focus on evaluating mercury release from land disposal.
2. Even when Category C wastes are placed on the land, a range of release scenarios and exposure pathways are of concern, not only leaching into groundwater.
3. Noting that Paragraph 3(c) of Article 11 provides for transboundary movement of mercury waste, a threshold linked to a particular management assumption, such as a leaching threshold, may not ensure the prevention of environmental and health risk in the receiving country with different exposure conditions and management practice.
4. There are internationally accepted protocols for measuring the level of mercury present based upon total concentrations. There is no comparable globally accepted leaching procedure for the large variety of Category C wastes managed under diverse conditions.

American Coal Ash Association Phone: 720-870-7897 38800 Country Club Drive Fax: 720-870-7889 Farmington Hills, MI 48331 Internet: www.ACAA-USA.org Email: info@aca-usa.org									
2019 Coal Combustion Product (CCP) Production & Use Survey Report									
Beneficial Utilization versus Production Totals (Short Tons)									
2019 CCP Categories	Fly Ash	Bottom Ash	Boiler Slag	FGD Gypsum	FGD Material Wet Scrubbers	FGD Material Dry Scrubbers	FGD Other	FBC Ash	CCP Production / Utilization Totals
Total CCPs Produced by Category	29,319,239	9,150,680	965,138	22,975,581	6,217,129	3,707,974	18,428	6,293,721	78,647,890
Total CCPs Used by Category	17,768,235	2,923,586	697,001	13,285,876	359,529	90,346	0	5,882,468	41,007,041
1. Concrete/Concrete Products (Grout)	12,604,878	332,036	0	95,090	0	10,300	0	0	13,042,304
2. Blended Cement/ Feed for Clinker	2,556,358	910,314	65,758	1,464,262	0	0	0	3,442	5,000,734
3. Flowable Fill	102,196	0	0	0	0	0	0	0	102,196
4. Structural Fills/Embankments	501,668	532,676	67,104	617,122	0	0	0	0	1,718,570
5. Road Base/Sub-base	154,822	105,869	0	0	0	0	0	0	260,690
6. Soil Modification/Stabilization	76,239	126,719	0	3,911	0	0	0	0	206,869
7. Mineral Filler in Asphalt	4,598	4,711	3,831	0	0	94	0	0	13,234
8. Snow and Ice Control	0	73,720	10,114	0	0	0	0	0	83,834
9. Blasting Grit/Roofing Granules	0	362,281	245,601	0	0	0	0	0	607,883
10. Mining Applications	17,282	0	0	0	0	0	0	5,831,652	5,848,935
11. Gypsum Panel Products (formerly Wallboard)	0	0	0	9,688,345	82,703	0	0	0	9,771,048
12. Waste Stabilization/Solidification	604,222	57,689	0	16,503	0	11,858	0	47,374	737,646
13. Agriculture	0	2,449	0	572,399	0	59,966	0	0	634,814
14. Aggregate	63,609	137	0	0	0	0	0	0	63,745
15. Oil/Gas Field Services	152,053	436	0	0	0	8,128	0	0	160,617
16. CCR Pond Closure Activities	720,411	357,558	304,592	713,573	276,826	0	0	0	2,372,960
17. Miscellaneous/Other	209,896	56,391	0	114,671	0	0	0	0	380,960
Summary Utilization to Production Rate									
CCP Categories	Fly Ash	Bottom Ash	Boiler Slag	FGD Gypsum	FGD Material Wet Scrubbers	FGD Material Dry Scrubbers	FGD Other	FBC Ash	CCP Utilization Total
Totals by CCP Type/Application	17,768,235	2,923,586	697,001	13,285,876	359,529	90,346	0	5,882,468	41,007,041
Category Use to Production Rate (%)	60.60%	31.95%	72.22%	57.83%	5.78%	2.44%	0.00%	93.47%	52.14%
2019 Censospheres Sold (Pounds)	943,603	Data in this survey represents 152 GW of Name Plate rating of the total industry wide approximate 236 GW capacity based on EIA's July 2019 Electric Power Monthly.							

I-Total concentration of mercury in waste

The use of total concentration of mercury identifies the presence of mercury in the waste and assumes that as a general matter the more mercury present, the higher its potential to cause adverse human health or environmental effects.

* The annex has not been formally edited.

I-1- Description of measurement method

a) Fast analysis of (multiple) (field) point

- Hand-held or benchtop X-Ray fluorimeter (EN 15309), preferably calibrated for the specific matrix of the analysed waste, usable for all the elements of the periodic table heavier than sulphur, or heavier than sodium with a specific detector. It is necessary to carefully measure the waste by hand-held X-ray fluorimeter to reduce an X-ray exposure dose as much as possible.
- Application to the surface of solid waste (wet or not), giving the local surficial mercury concentration; typically, multiple measurements at different locations are performed
- Duration: 30 seconds per spot of about 25 mm²
- Limit of detection (LOD = 3 x s; s = standard deviation of (≥ 10) repeated measurement of material without mercury; measurements with concentrations between LOD and LOQ are qualitative and indicative of presence) for field handheld XRF: 1 mg/kg dry matter. Limit of quantification (LOQ = 10 x s; measurements > LOQ are quantitative) for field handheld XRF: 3 mg/kg dry matter
 - **Concentration of total Hg in single or multiple spots of the waste**, and calculation of a mean concentration. Shows the eventual heterogeneity, important for representative sampling. Can be used for sorting waste pieces on-line by their mercury concentration, eventually in automated systems on streams (available on the market).

b) Laboratory analysis of mean representative sample of batch or stream

- Representative sampling on the field from the waste piece, heap or stream to the laboratory sample. The laboratory sample ranges from 0.1 to 100 kg depending on the size and weight of the individual particles composing the material: it should contain about 10 000 particles to measure the 99th percentile of the mercury distribution in the particles if the coefficient of variation of particle analysis is 10% (CEN/TR 15310-1). If the concentration of mercury is dependent of the size of the particles (for instance if mercury is present as a separated mineralogical phase of a given size range), the Gy's equations (ISO 11648-2) should be used.
- Pre-treatment at the laboratory to obtain a representative test portion of about 1 g to 10 g (drying at temperature < 40°C if necessary, size reduction - crushing, shredding, cutting, milling - if necessary, in one or more steps, mixing, quartering)
- Three methods of measuring concentration:
 - Extraction/digestion of the test portion (1 g) by hot acids in closed vessels (EN 13657 or ISO 11466), and dosage by laboratory cold-vapor atomic fluorescence (ISO 16772), or other dosage method
 - Direct analysis of a prepared (homogenized to be representative) test portion (10 g) by hand-held or benchtop X-ray fluorimeter (EN 15309)
 - Direct combustion analysis of the test portion (< 0.3g) by thermal decomposition method (USEPA 7473; ASTM D 6722-19; ASTM D 7623-20)
- Duration: 1 day – 1 week
- Limit of quantification LOQ (LOD = 1/3 LOQ):
 - 0.03 mg / kg dry matter by atomic absorption in cold vapor (EN 16175-1)
 - 0.003 mg / kg dry matter by atomic fluorescence in cold vapor (EN 16175-2)
 - 0.1 mg / kg dry matter by optical ICP
 - 0.02 mg / kg dry matter by ICP MS (mass spectrometry)
 - 0.01 ng of total mercury (thermal decomposition method)

Availability of measurement apparatuses

These apparatuses are available on the market.

Hand-held or benchtop fluorimeters are frequently used in mining and metallurgy companies, including secondary metallurgy recycling waste companies, to assess quality of the scraps.

Cold-vapor atomic absorption spectrometers and fluorimeters are frequently used in universities, technical centres and service laboratories analysing industrial and environmental samples.

Cost for measurement

- Field Hand held XRF (multi-element)
 - Cost of apparatus 30,000 USD
 - Cost of one analysis 2 - 10 USD depending on labor cost (60 analyses per hour)
- Laboratory bench-top wave dispersion X-ray fluorimeter (multi-element)
 - Cost of apparatus 80,000 USD
- Laboratory Extraction and dosage
 - Extraction (also called digestion)
 - Heating plate for acid digestion and reflux with cooler 12 samples (multi-element) 10,000 USD, or

- Microwave oven for acid digestion (multi-element) 50,000 USD.
- Dosage
 - Atomic absorption in cold vapor (Hg only) 40,000 USD, or
 - Atomic fluorescence in cold vapor (Hg only) 40,000 USD, or
 - Optical ICP (multi-element) 70,000 USD, or
 - ICP MS (multi-element) 150,000 USD.
- Laboratory Cold vapor
 - Cost of the apparatus (digestion, measurement) 50,000-200,000 USD or USD 15,000-25,000 for cold-vapor atomic absorption spectrometer without digestion
 - Cost of one sample preparation and analysis
 - Granular waste that crush 20 – 30 USD
 - Plastics shreds, metals scraps 100 USD
- Thermal decomposition method
 - Cost of the apparatus (measurement) 23,000-45,000 USD
 - Cost of one analysis 3-5 USD depending on labor cost (6-10 analyses per hour)

I-2- Standards

- CEN/TR 15310-1: 2007. Characterization of waste — Sampling of waste materials — Part 1: Guidance on selection and application of criteria for sampling under various conditions.
- EN 13657: 2003. Characterization of waste - Digestion for subsequent determination of aqua regia soluble portion of elements.
- EN 15309: 2007. Characterization of waste and soil — Determination of elemental composition by X-ray fluorescence.
- ISO 11466: 1995. Soil quality- Extraction of trace elements soluble in aqua regia.
- ISO 11648-2:2001. Statistical aspects of sampling from bulk materials - Part 2: Sampling of particulate materials.
- ISO 16772: 2004. Soil quality - Determination of mercury in aqua regia soil extracts with cold-vapour atomic spectrometry or cold-vapour atomic fluorescence spectrometry.
- HJ 923-2017. Soil and sediment - Determination of total mercury - Catalytic pyrolysis - cold atomic absorption spectrophotometry
- HJ 702-2014. Solid Waste - Determination of Mercury, Arsenic, Selenium, Bismuth, Antimony - Microwave Dissolution / Atomic Fluorescence Spectrometry
- HJ 680-2013. Soil and sediment - Determination of Mercury, Arsenic, Selenium, Bismuth, Antimony - Microwave dissolution / Atomic Fluorescence Spectrometry
- GB/T 15555.1-1995 Solid waste - Determination of total mercury - Cold atomic absorption spectrometry
- USEPA 7473 Mercury in Solids and Solutions by Thermal Decomposition Amalgamation, and Atomic Absorption Spectrophotometry
- ASTM D 6722-19: Total Mercury in Coal and Coal Combustion Residues by Direct Combustion Analysis
- ASTM D 7623-20: Total Mercury in Crude Oil Using Combustion-Gold Amalgamation and Cold Vapor Atomic Absorption Method

II- Release potential of mercury in a waste (leaching test)

When a category C waste has been identified as a mercury waste for the purpose of the Minamata Convention, criteria and testing methods should apply accordingly depending on the waste management routes and the exposure scenarios. Several standardised leaching tests have been developed in order to assess possibility of disposal in landfills or on land.

Measures of release potential of mercury in a waste could be based on the form of mercury in the waste or aspects of the waste matrix that facilitate or retard release to the environment and may be an appropriate basis for emission levels for some wastes. Measures of release potential are, however, linked to particular management conditions (e.g., leach testing to assess groundwater contamination potential of wastes managed on land) and any single test may not address all release pathways.

II-1- Description of measurement methods

Leaching tests can be described in two general categories:

- Scenarios: the test reproduces on a small scale in the laboratory the present and future conditions that are anticipated to prevail during the life of the waste with the management options. This work can be done on a larger

scale in lysimeters, collecting runoff and drainage water from exposed waste with planned waste management. A test mimics the present or future situation;

- Characterization: the tests establish the physical or chemical characteristics of the waste / leachant couple, which characterize the mobilization and transfer of the elements with time and the liquid to solid ratio, and can be used to generalize the results and use them in modeling the future of waste constituents. More than one test are needed for full characterization: usually a leach test (with a leachate), a percolation test (with collection of different leachate fractions with time and L / S), a pH dependent test (with collection of the fraction at forced pH), and some adsorbent / desorbent fractions of the waste (iron and aluminum oxyhydroxides, speciation of solid and suspended organic matter).

Note on the EU leaching tests EN: The leachant is deionized water used at 2 l/kg or more frequently at 10 l/kg. Non-monolithic material is ground to 4 or 10 mm and the flasks are agitated. The leachates are filtered at 0.45 µm. The leaching tests last for 24 h and the percolation test for about 1 month (depending on the mass in the 5-cm or 10-cm diameter column, length 30 cm), with a residence time of about 1 day, to be close to solid/liquid equilibrium. These tests have been extended with some variants to soil and construction material. They are used routinely for landfill acceptance and for assessment of potential emission to water.

The US has developed a series of waste leaching tests that include many of the features of the EU leaching tests. These tests (US EPA Methods 1313-1316) evaluate the intrinsic properties of the waste that affect leaching, including constituent release over a range of pH conditions, rate of release based on water infiltration rate, and the porosity of solid materials. These methods can be used to evaluate pollutant release potential for waste as-generated or when treated to reduce contaminant mobility.

In China, the most widely used leaching tests (HJ/T 299 and HJ/T 300) have been applied to simulate the process of harmful components leaching into the environment under different scenarios. The main purpose of HJ/T 299-2007 is to simulate heavy metals' leachability by acid precipitation. The HJ/T 300-2007 test is used to simulate heavy metals' leachability and mobility when the waste is landfilled. HJ 577-2010 and GB 5086.1-1997 are also used as leaching tests in China. They both use water as leaching agent to simulate the process of waste being leached from surface water or groundwater in a specific occasion, and the harmful components there in are leached into the environment.

Japanese leaching tests No.13: The leachant is deionized water used at 10 l/kg. Wastes with more than 5 mm in particle diameter are ground to less than 5 mm, and the grinding preparation for fine wastes such as burnt residues, sludge and dusts is not necessary. The flask containing leachant and prepared waste is shaken at about 20 degree Celsius and 200 rpm for 6 hours. The leachate is separated centrifugally and filtered with 1 µm membrane filter. This method is used routinely for landfill acceptance of wastes.

II-2- Standards

- EN 12457-1 to 4: Characterization of waste - Leaching - Compliance test for leaching of granular waste materials and sludges (CEN, 2002a)
- EN 12920: Characterization of waste - Methodology for the determination of the leaching behaviour of waste under specified conditions (CEN, 2006)
- EN 13656: Characterization of waste - Microwave assisted digestion with hydrofluoric (HF), nitric (HNO₃) and hydrochloric (HCl) acid mixture for subsequent determination of elements in waste (CEN, 2002b)
- EN 13657: Characterization of waste - Digestion for subsequent determination of aqua regia soluble portion of elements in waste (CEN, 2002c)
- EN 14405: Characterization of waste - Leaching behaviour test - Up-flow percolation test (under certain conditions) (CEN, 2017)
- USEPA METHOD 1313 Liquid-solid partitioning as a function of extract pH using a parallel batch extraction procedure. <https://www.epa.gov/hw-sw846/sw-846-test-method-1313-liquid-solid-partitioning-function-extract-ph-using-parallel-batch>
- USEPA METHOD 13141 Liquid-solid partitioning as a function of liquid-solid ratio for constituents in solid materials using an up-flow percolation column procedure. <https://www.epa.gov/hw-sw846/sw-846-test-method-1314-liquid-solid-partitioning-function-liquid-solid-ratio-constituents>
- USEPA METHOD 1315 Mass transfer rates of constituents in monolithic or compacted granular materials using a semi-dynamic tank leaching procedure. <https://www.epa.gov/hw-sw846/sw-846-test-method-1315-mass-transfer-rates-constituents-monolithic-or-compacted-granular>

- USEPA METHOD 1316 Liquid-solid partitioning as a function of liquid-to-solid ratio in solid materials using a parallel batch procedure. <https://www.epa.gov/hw-sw846/sw-846-test-method-1316-liquid-solid-partitioning-function-liquid-solid-ratio-solid>
- HJ 702-2014 Solid Waste - Determination of Mercury, Arsenic, Selenium, Bismuth, Antimony - Microwave Dissolution / Atomic Fluorescence Spectrometry
- HJ/T 299-2007 Solid waste - Extraction procedure for leaching toxicity - Sulphuric acid & nitric acid method
- HJ/T 300-2007 Solid waste - Extraction procedure for leaching toxicity - Acetic acid buffer solution method
- HJ 557-2010 Solid waste - Extraction procedure for leaching toxicity - Horizontal vibration method
- Ministry of the Environment, Japan (1973): Analytical Method of Heavy Metals Contained in Industrial Wastes - Ministry of the Environment Notification No. 13 (Japanese Leaching test No.13).

III- Qualitative determination (listing approach)

The listing approach would necessitate identifying and naming the wastes falling within category C. Category C waste represents a very diverse group of wastes, however, originating from a wide variety of sources, and containing different amounts of mercury. As a catch-all category, category C would provide an indicative list for guidance purposes rather than a definitive list specifying the boundaries of legal obligations. Accordingly, the listing approach could not be the sole basis for setting thresholds for the coverage of mercury waste under article 11.

Annex II

Technical calculation of a proposed threshold for tailings from industrial-scale non-ferrous metal mining other than primary mercury mining, based on leach testing*

Introduction

The group of technical experts established pursuant to decision MC-2/2 of the Conference of the Parties to the Minamata Convention proposes the following two-tiered thresholds for tailings from industrial-scale non-ferrous metal mining other than primary mercury mining:

- Tier-1 threshold to be applied first: 25 mg/kg total mercury content;
- Tier-2 threshold to be applied to tailings above the tier-1 threshold: 0.15 mg/L in the leachate using an appropriate test method simulating the leaching of mercury at the site where the tailings are deposited.

This document describes the technical calculation leading to the proposed tier-2 thresholds. The proposals considered by the group of technical experts, as described below, are available from the website of the Minamata Convention:

<https://www.mercuryconvention.org/en/meetings/cop4#cop-intersessional-work>

Two proposed models

As part of the efforts to establishing a Tier 2 leaching threshold for non-ferrous mine tailings under the Minamata Convention, two models were put forward looking at the transport of mercury in groundwater through soils.

One expert presented a proposal (Hennebert, 2021) including transport of mercury in a vadose zone (unsaturated groundwater zone) underlying the tailings, paired with a two-dimensional (2D) groundwater model that accounted for dispersion, or dilution, in the direction of flow as well as in the direction lateral to flow in order to calculate a dilution and attenuation factor (DAF) at the compliance point. That model has been used in 1998-2000 to calculate the maximum leaching concentration of waste for landfill acceptance in the European Union.

Another expert submitted a report prepared for the International Council of Mining and Metals (Ecometrix, 2021). The model used in that report followed the same logic as in Hennebert (2021) to determine a DAF for mercury, including the same leaching function but with no migration through the vadose zone. This resulted in a simpler but more conservative one-dimensional (1D) groundwater transport model that includes dilution/dispersion in the flow direction only, ignoring the additional diluting effect that would be observed in the 2D model. As a result, the Ecometrix 1D model is inherently more conservative.

The group of technical experts considered Tier-2 thresholds based on the Ecometrix 1D model, also referring to the 2D model in Hennebert (2021).

Description of the one-dimensional model

Conceptual Model

Water that enters the tailings as rainfall or snowmelt moves downward through the pore spaces as it would in the natural ground. The water that contacts the tailings can then leach substances such as mercury and carry those substances in dissolved form down towards the groundwater table. The leaching of the mercury is assumed so that the relatively highest concentrations occurring initially and the leach concentrations decreasing with increasing volumes of water contacting the tailings solids. The model is based on a conservative assumption that the leach solution enters the groundwater zone at the base of the tailings. The transport of mercury through groundwater is represented by a one-dimensional (1-D) advective dispersive groundwater transport model with retardation. The point of compliance (POC) is assumed to represent a water supply well at a distance of 200 m from the tailings where a human can ingest water.

Context for Drinking Water

A maximum drinking water concentration for mercury can be selected for a criterion that should not be exceeded at the POC. The World Health Organization has a drinking water limit of 0.006 milligrams of mercury (Hg) per litre of

* The annex has not been formally edited.

water (mg/L) and that value was proposed for the criterion. This means that if the mercury concentration in groundwater at 200 metres from the tailings remains below 0.006 mg/L then the tailings will be classified as not a mercury waste and no further action is required.

Mercury Leaching from Tailings

The model uses a leaching function that calculates the concentration of a leached constituent as a function of the ratio of the cumulative water or liquid to solids (L/S). As more water contacts the solids, the leached concentration decreases. The L/S ratio is also a function of time because water flowing through the tailings is a function of natural precipitation falling on the tailings. A portion of the precipitation enters and flows through the tailings. The model assumes 300 millimetres of drainage per annum (300 litres per square meter of material section). In a 20 m thick tailings deposit, with a density of 1,500 kg per cubic metre (kg/m^3), the L/S ratio will be 300 litres (L) drainage per 30,000 kg solid each year or 1:100. Therefore, after 100 years, the cumulative L/S ratio will be 1:1. The concentration (C) at a L/S value is described with the equation;

$$C = C_0 e^{-(L/S) \cdot K}$$

In which C_0 is the initial and maximum concentration, and K is a unitless factor that represents the rate of decline in the leach concentration with L/S. Some example data were reviewed for the leaching behaviour of elements from waste rock in order to assess an appropriate K factor for mine materials. Data for mercury could not be evaluated because the concentrations of mercury in the leach solutions were below the analytical detection limit of 0.002 mg/L throughout the study. Therefore, other trace elements that had detectable concentrations in the leach solutions, including cadmium, selenium, uranium and zinc, were considered and a plot of absolute concentrations as a function of L/S is shown in Figure 1. The data show that the concentrations decrease as expected with increasing L/S. While there is some scatter in the zinc concentrations at higher L/S values, the trends for the four elements are similar and consistent.

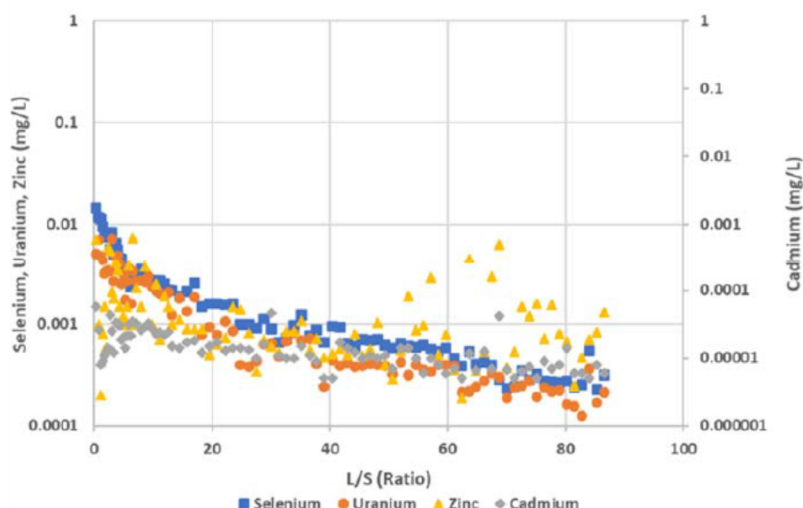


Figure 1: Measured concentrations of selected elements with L/S for leaching of a waste rock sample.

The concentrations were normalized (divided by the initial leaching concentration C_0) and C/C_0 was plotted against L/S to compare to the leaching model calculations as shown in Figure 2. The K value of 0.05 presented in Hennebert (2021) provides a reasonable representation of the data for the four elements in the leach test as shown by the black curve. The K values of 0.02 and 0.08 are shown for comparison and bracket the data. This suggests that the leaching model and K factor of 0.05 presented in Hennebert (2021) can be used to describe the leaching of an element like mercury from mine waste including tailings.

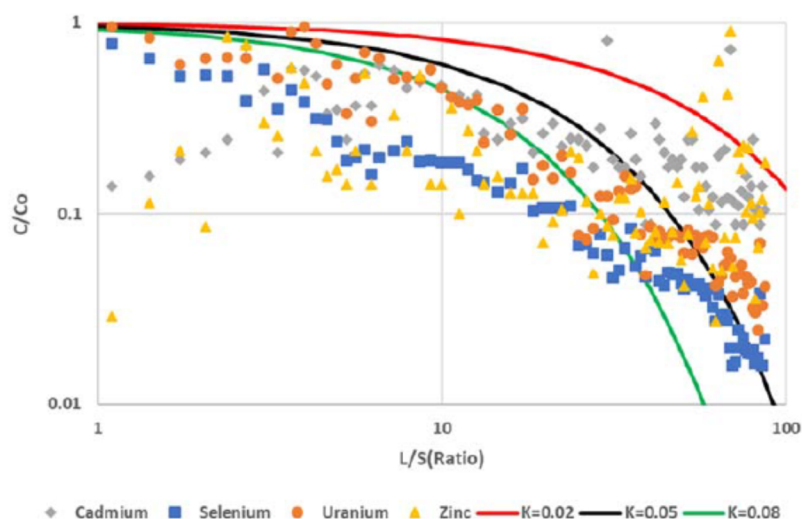


Figure 2: Plot of normalized concentrations (C/C_o) versus L/S for leaching of a waste rock sample.

The leaching function provides a source term for mercury from the tailings. The normalized source concentrations as a function of time are shown in Figure 3. As noted above, the cumulative L/S value of 1 litre of water per kg of tailings is equivalent to 100 years of infiltration at a rate $0.3 \text{ m}^3/\text{m}^2/\text{a}$ (300mm/a) and therefore the L/S value of 100 is equivalent to 10,000 years of infiltration and leaching.

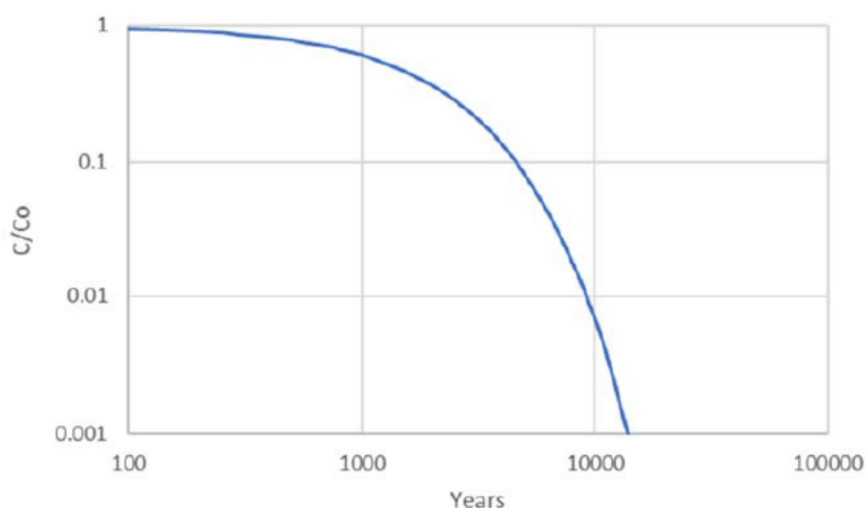


Figure 3: Normalized mercury concentrations leaving the tailings as a function of time

Groundwater Flow

The water leaving the base of the tailings is assumed, conservatively to enter the groundwater directly with no vadose zone pathway between tailings and the water table. The properties assigned to the groundwater flow and transport are summarized in Table 1. A travel distance to the point of compliance is assumed to be 200 m from the tailings. With the assigned value of $1 \times 10^{-5} \text{ m/s}$ for the hydraulic conductivity and a hydraulic gradient of 0.01 (1%), the volumetric flux is 3.15 m/a . With an effective porosity of 0.3, the average linear groundwater velocity is 10.5 m/a .

Table 1: Properties related to groundwater transport

Parameter	Unit	Value
Length of Flow Path	m	200
Hydraulic Conductivity	m/s	1×10^{-5}
Hydraulic Gradient	m/m	0.01
Volumetric Flux	$\text{m}^3/\text{m}^2/\text{a}$	3.15
Effective Porosity	-	0.3
Longitudinal Dispersivity	m	20

Partitioning Coefficient (K_d)

A review of the literature was completed to determine the potential values for solids-water partitioning coefficients for inorganic mercury that may apply to the natural geologic materials (soils) through which groundwater flow is expected to occur. A wide range of K_d values for inorganic mercury partitioning coefficients was observed in the literature, across a broad range of soil types, textures and pH values. As explained below, model calculation was conducted using different K_d values.

Groundwater Transport

The transport of mercury through groundwater is represented by a one-dimensional (1-D) advective dispersive groundwater transport model with retardation. The model includes advection, dispersion, linear equilibrium-sorption (retardation) and first-order transformation reaction. No transformation reaction was used in this modelling assessment. The model includes specified concentration inflow boundary conditions with a general time-varying reservoir concentration and a semi-infinite domain. A schematic representation of the 1-D advective-dispersive groundwater model is shown in Figure 4.

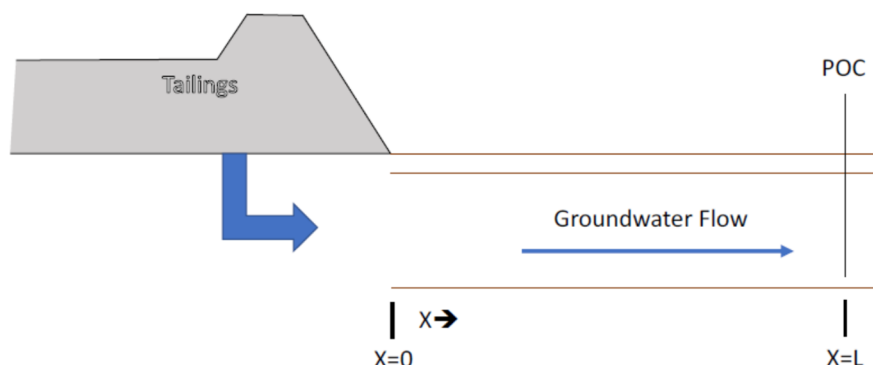


Figure 4: Schematic representation of the 1-D groundwater model

Model calculation

The 1D model was applied to K_d values with a range of probabilities in order to select a reasonably conservative DAF value. The results are summarized in Table 2. The percentile described in the table represents the probability that a K_d value will be greater than the value listed. For example, a percentile of 5% indicates that there is a probability of 5% that K_d values for soil or geologic materials will be less than the listed value of 133 L/kg or, conversely, that there is a probability of 95% that values will be equal to or greater than 133 L/kg. Table 2 lists the resulting DAF values and the corresponding leach concentrations of mercury based on the WHO drinking water standard of 0.006 mg/L.

Table 2: Comparison of DAF and leach concentration values for 1D model and prorated 2D model results for selected K_d values.

Percentile of K_d data in the literature	Corresponding K_d value	DAF – 1D Model	Prorated DAF – 2D Model	1D Model leach concentration	Prorated 2D Model leach concentration
%	(-)	(L groundwater/ L leachate)	(L groundwater/ L leachate)	mg/L leachate	mg/L leachate
5%	133	6.7	24.4	0.04	0.15
10%	246	10.9	39.7	0.07	0.23
20%	520	22.0	80.1	0.13	0.48
40%	1,408	54.3	198	0.33	1.18
50%	2,164	77.3	281	0.46	1.69

Table 2 also compares the DAF values and leach concentrations for the results of the ICM 1D model and the prorated 2D model. Hennebert (2021) calculated a DAF of 4 given its use of a K_d value of 1 L/kg and the 2D model; this DAF would be only of a value of 1.1 with the 1D model – a factor that is 3.64 times lower. To be able to compare

the results from the two approaches, the 1D DAF was prorated by multiplying the DAF by a factor of 3.64 to show the equivalent 2D model's DAF.

Using the 20th percentile of the Kd value (520 L/kg) results in a DAF of approximately 20 for the 1D model, corresponding to the leaching concentration of 0.13 mg/L to achieve WHO drinking water limit of 0.006 mg/L. If the same Kd were applied to the 2D model, prorated results provide a DAF of almost 80 for the same Kd. Using the 5th percentile of the Kd value (133 L/kg) results in a DAF of approximately 20 under the prorated 2D model, corresponding to the leach concentration of 0.15 mg/L leachate (= 0.006 mg Hg/L groundwater x 24.4 L groundwater/L leachate = 0.1464 mg Hg/L leachate, rounded to 0.15 mg Hg/L leachate) to achieve WHO drinking water limit of 0.006 mg/L, similar to the 1D model for 20th percentile Kd of 520.

Based on this calculation, the group of technical experts recommended a tier-2 threshold of 0.15 mg/L leachate.
