Proposed Post-Closure Non-Radiological Acceptance Criteria for the Protection of Persons and the Environment

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Nuclear Waste Management Organization

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ABSTRACT

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Abstract
The purpose of this report is to present the basis for proposed acceptance criteria for the protection of persons and the environment from non-radiological releases (i.e., potentially hazardous chemical elements) during the post-closure phase of the Adaptive Phase Management (APM) Deep Geological Repository (DGR) project. The criteria are based on Canadian Federal and Ontario Provincial guidelines and publications, supplemented as required by internationally developed guidelines. Criteria are provided for five environmental media: surface water, groundwater, soil, sediment and air. They are proposed for use by APM DGR project post-closure safety assessments.

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1. INTRODUCTION

This document presents the basis for proposed acceptance criteria to be used as reference values to assess the impact of the APM DGR project on human health and the environment from the potential release of non-radiological contaminants in post-closure safety assessments. They have been assembled taking into account the guidance of CNSC REGDOC-2.11.1 (Vol III) (CNSC 2021).

In the Canadian context, several generic post-closure safety assessments examined the safety implications of a hypothetical deep geological repository for used fuel, each considering variations in the repository design and site characteristics. The main emphasis of these safety assessments was on the radiological consequences, due to the radiological hazard of the used fuel. However, because a repository contains a variety of other materials, some of which are chemically toxic in large enough quantities, analyses of hazards to people and the environment from non-radiological contaminants are also included in post-closure safety assessments.

There is no single authoritative reference with criteria for all relevant elements for the assessment of effects from a deep geological repository. Atomic Energy of Canada Limited (AECL) originally developed criteria for evaluating the chemical toxicity of elements released from a used fuel repository in the Environmental Impact Statement case study (AECL, 1994; Goodwin and Mehta 1994). Ontario Power Generation (OPG) revised these criteria for three environmental media (water, soil and air) in the Horizontal Borehole Concept Case Study (Garisto et al. 2005). The criteria were based on Canadian federal and provincial guidelines, international guidelines, peer-reviewed reports, and values derived from chemotoxicity data for rats and mice. The NWMO provided the subsequent update, which added criteria for sediment and the differentiation between surface water and groundwater criteria. These criteria were used in generic post-closure safety assessments for hypothetical sites in crystalline (NWMO, 2012) and sedimentary (NWMO 2013) rock environments.

In 2015, the NWMO published a comprehensive set of acceptance criteria for surface water, groundwater, soil, sediment and air (Medri 2015), which provided criteria for all elements in the periodic table except for those without chemical toxicity and those for which benchmarks were not identified in reference documents and literature. These were used in subsequent generic safety assessments for hypothetical sites in crystalline (NWMO 2017) and sedimentary (NWMO 2018) rock environments. Lastly, to fill some criteria gaps in Medri (2015), Fernandes et al. (2019) developed acceptance criteria for elements screened into the 2017 and 2018 post-closure safety assessment.

The current report presents the proposed acceptance criteria in surface water, groundwater, soil, sediment and air for the 17 elements identified as potentially important for post-closure safety assessment according to the Fuel Radiotoxicity and Screening Analysis (Gobien et al. 2021).The criteria are generally similar to the criteria adopted in Ontario Power Generation's licence application for a proposed Deep Geologic Repository (OPG DGR) for Low and Intermediate Level Waste (Quintessa et al. 2011).

These acceptance criteria are intended for the post-closure phase in that they are selected for chronic exposure conditions. They are proposed for use by APM DGR post-closure safety assessments.

2. SAFETY ASSESSMENT APPROACH

As defined by CNSC (2021), a safety assessment is defined as an assessment of all aspects relevant to the safety of a nuclear facility. It follows an interactive approach that carries on throughout the design process and over the lifecycle of the facility or the activity, to ensure that all relevant safety requirements are met (CNSC 2021). The CNSC (2021) requires that acceptance criteria be developed, which serve to determine whether the safety assessment results are acceptable. These are to be developed for the protection of persons and the environment from both radiological and non-radiological contaminants.

The proposed acceptance criteria described in this report are reference values to assess the potential impact of the repository on human health and the environment from non-radiological release estimated by post-closure safety assessments. Application of these criteria will depend on the analysis context.

Acceptance must be evaluated within the context of the likelihood of the scenario (e.g., normal evolution vs disruptive event scenarios), the conservatism in the proposed acceptance criterion (e.g., through reference to original sources as identified here), the application of the criteria to the protection or populations vs individuals and the conservatism in release and exposure models.

Lastly, it is important to acknowledge that there may be synergistic, additive, or antagonistic effects from species in mixtures. The criteria presented herein do not consider these effects. The combined effect of non-radiological elements is usually assumed to be additive. Further consideration of the potential for combined effects should occur at the safety assessment stage.

3. METHODOLOGY FOR DEFINING ACCEPTANCE CRITERIA

Acceptance criteria were developed following the CNSC REGDOC-2.11.1 (Vol III) guidance (CNSC 2021). They are defined for chronic environmental exposures, which are characteristics of the types of exposures during the post-closure phase. They are protective of the following features for each medium:

Surface water: drinking water, aquatic life, agricultural water uses (irrigation and livestock), recreational water uses and aesthetic features.

Groundwater: drinking water, agricultural water uses (irrigation and livestock) and surface water bodies from groundwater baseflow.

Soil: ecological receptors and human health for soils for various land uses (agricultural, residential/parkland, commercial and industrial).

Sediment: aquatic life, human health and the environment.

Air: human health, the environment and nuisance effects (like odor).

The methodology for defining acceptance criteria is described in Table 3-1. Criteria were selected from four different tiers. The top tiers use well-established benchmarks and thus the criteria from these tiers have little uncertainty, whereas the criteria from the bottom tiers have more uncertainty.

Table 3-1: Methodology for Defining Acceptance Criteria

Step	Description
Step 1: **Create reference document hierarchy**	Reference documents were binned into three tiers, following the guidance of CNSC (2021). The three tiers were as follows**:** **Tier 1 (Primary References):** The Canadian Council of Ministers of the Environment (CCME) guidelines are the top priority references. The primary references are therefore the suite of guidelines offered by the CCME (i.e., Water Quality Guidelines for the Protection of Aquatic Life, Water Quality Guidelines for the Protection of Agriculture, Soil Quality Guidelines for the Protection of Environmental and Human Health, and Sediment Quality Guidelines for the Protection of Aquatic Life) **Tier 2 (Secondary References):** The federal and provincial guidelines and standards are the next priority. As both candidate sites in the site selection process are in Ontario, the only provincial references included in this report are from Ontario. **Tier 3 (Tertiary References):** In the absence of CCME guidelines and federal/provincial guidelines, guidelines and standards from other jurisdictions or criteria derived using toxicity data may be used. The references for each tier are described in more detail in Section 4.
Step 2: **Select acceptance criteria from hierarchy of references**	For as many element/media combinations as possible, the most appropriate benchmark/guidelines for use as acceptance criteria were selected. Most often, this corresponded to the minimum of all benchmarks. Where guidelines are presented for separate species (e.g., trivalent or hexavalent chromium), the lowest criterion was adopted. Where guidelines are presented for compounds with the same element, the criterion for the dominant element was adopted (for example, in some cases, for mercury, the criterion is for methyl mercury since methyl mercury is more limiting than elemental mercury). In some cases, a less restrictive benchmark may be justified, using expert judgement. For example: - Minimum benchmarks that are not applicable to post-closure repository conditions; - Benchmarks that are given with context (e.g., water pH or hardness); and - Benchmarks that are not intended as screening criteria are available within the same tier of references as the minimum benchmark. For the element/media combinations for which criteria were not identified in the primary references, the most appropriate benchmark from secondary, then tertiary, references were selected.

Step	Description
Step 3: **Apply surrogate approach to missing criteria**	For the element/media combinations for which no criteria were identified in the primary, secondary or tertiary references, a surrogate approach was applied. **Tier 4 (Surrogate):** Criteria were derived using the following steps, similar to the surrogate approach recommended by Fernandes et al. (2019). 1) <u>Use of surface water criteria to derive groundwater criteria</u> In alignment with MOE (2011), Fernandes et al. (2019) recommends the application of a conservative, order of magnitude dilution factor of 10 for the derivation of groundwater criteria for the protection of aquatic life, acknowledging that dilution will occur when groundwater discharges to surface water. This factor is only applied for elements that are known to be non-toxic to humans. For elements with suspected or known toxicity to humans, no dilution factor was applied. 2) <u>Interchange of soil and sediment criteria</u> Sediment and soil criteria are interchanged one for one, since the two media are similar. 3) <u>Use of acute benchmarks in air</u> In the absence of appropriate chronic air benchmarks, acute air benchmarks are adopted as acceptance criteria. 4) <u>Chemical analogues to fill the remaining gaps</u> Chemical analogues were identified by finding elements with similar chemical properties. Elements in the same group (column) of the periodic table usually exhibit similar chemical behaviours because they have the same number of outer electrons available to form chemical bonds (i.e., they form compounds in the same valence state) (IAEA 2009). Transition elements in the same period (row) of the periodic table also tend to be chemically similar. A key use of surrogates is within the rare earth elements, which are chemically similar.

4. SOURCES OF ACCEPTANCE CRITERIA

This section presents the sources of references in Tiers 1, 2 and 3, as described in Table 3-1.

4.1 Tier 1: Primary References

The primary references, as recommended by CNSC (2021), are the guidelines that are published by the Canadian Council of Ministers of the Environment (CCME).

The Canadian Environmental Quality Guidelines (CCME 2021a, b, c, d) integrate national quality guidelines for all media including water, soil, sediment and air. They are derived for the protection of various water, soil, sediment and air uses and are based on the current, scientifically defensible toxicological data available. The Canadian Environmental Quality Guidelines were developed in part because of the success of the Canadian Water Quality Guidelines, which were published in 1987 by a predecessor of the CCME.

The relevant guidelines are described as follows:

1) **The Canadian Sediment Quality Guidelines for the Protection of Aquatic Life (CCME, 2021a)**
   Applicable to: Sediment

   These guidelines provide scientific benchmarks for evaluating the potential of adverse biological effects in aquatic systems. They are derived using contaminated sediment field data from North America. Chemical and biological data were evaluated from numerous studies to establish an association between the concentration of each contaminant in the sediment and adverse biological effects.

2) **The Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health (CCME, 2021b)**
   Applicable to: Soil

   These guidelines protect ecological receptors in the environment and human health associated with four land uses: agricultural, residential/parkland, commercial and industrial. The lowest criteria for all these types of land uses are cited from this report.

3) **Canadian Water Quality Guidelines for the Protection of Agricultural Water Uses (CCME, 2021c)**
   Applicable to: Groundwater and Surface Water

   These guidelines are for protecting crops and livestock from contaminated irrigation and livestock drinking water and are designed to protect the most sensitive crop species. The lowest of the irrigation and livestock drinking water values are cited from this report.

4) **The Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME, 2021d)**
   Applicable to: Surface Water

   These guidelines are for protecting all forms of aquatic life and all aspects of the aquatic life cycle, including the most sensitive life stage of the most sensitive species over the long term. Criteria are presented for freshwater and saltwater, but only the freshwater values are cited in this report since it is not anticipated that the repository will be sited near saltwater.

4.2 Tier 2: Secondary References

The secondary references include federal (Canadian) and provincial (Ontario) guidelines, excluding the CCME guidelines. At the time of publication of this report, only communities from Ontario are included in the site selection process. Therefore, provincial guidelines in the secondary references are only from Ontario. Below is a description of the available references.

It is noted that while HC (2020), GC (2012) and MOE (1993) are listed below as secondary references for completion, benchmarks from these three references were not adopted as acceptance criteria after application of the methodology described in Section 3 (i.e., their benchmarks were not the minima among those of the secondary references and were not applicable as less restrictive alternatives to the minimum benchmarks).

1) **Federal Contaminated Sites Action Plan (GC 2012)**
Applicable to groundwater criteria

The Federal Contaminated Sites Action Plan (FCSAP) was established to help federal departments, agencies and consolidated Crown corporations address federal contaminates sites, to reduce environmental and human health risks as well as federal financial environmental liability associated with the higher risk federal contaminated sites. The guidelines in the report are based on a review of existing approaches for deriving groundwater quality guidelines used by other jurisdictions in Canada and in other countries. The study was conducted under the guidance of an Environment Canada working group of experts and reviewed by the Expert Support Science Department of Health Canada and Fisheries and Oceans. However, none of the guidelines were adopted as acceptance criteria since they were not the minima among the secondary reference benchmarks and were not applicable as less restrictive alternatives to the minimum benchmarks.

2) **Ontario Drinking Water Quality Standards, under Ontario Regulation 169/03 (GO 2018)**
Applicable to surface water and ground water criteria

This document prescribes the drinking water quality standards for the purposes of the Safe Drinking Water Act (GO 2002).

3) **Air Pollution – Local Air Quality Standards, under Ontario Regulation 419/05 (GO 2021)**
Applicable to air criteria

This document provides a list of air standards, guidelines and upper risk thresholds that form the Point of Impingement (POI) limits that are used to assess air quality in the vicinity of a single industrial or commercial facility in Ontario. The standards are based on human health, environmental effects or nuisance effects such as odour. They are primarily intended to be used by a single facility, as opposed to assessing the general air quality from all sources, like the AAQCs.

4) **Guidelines for Canadian Drinking Water Quality (HC 2020)**
Applicable to surface water and groundwater criteria

These guidelines are established by the Federal-Provincial-Territorial Committee on Drinking Water and published by Health Canada. Each guideline was established based on current, published scientific research related to health effects, aesthetic effects, and operational considerations. Protection of the environment is not addressed by these guidelines. Since groundwater is assumed to be drawn from a well and used for drinking, these guidelines are applicable as groundwater criteria. However, none of the guidelines were adopted as acceptance criteria since they were not the minima among the secondary reference benchmarks and were not applicable as less restrictive alternatives to the minimum benchmarks.

5) Soil, Groundwater and Sediment Standards for use under Part XV.1 of the Environmental Protection Act (MOE 2011)
Applicable to soil, groundwater, and sediment

These standards present standards for environmental assessments for various site conditions in Ontario (for example, background conditions and generic conditions, potable and non-potable conditions, stratified and non-stratified conditions, etc.) for soil, groundwater and sediment. The most conservative standards are those for the Full Depth Background Conditions (Table 1 of MOE 2011). For these conditions, the soil and sediment standards are within the range of background concentrations and provide a level of human health and ecosystem protection consistent with background conditions and protective of sensitive ecosystems (MOE 2011). The Full Depth Background Condition guidelines for soil are considered representative of upper limits of typical province-wide uncontaminated background concentrations in soils. The soil standards for "Agricultural and Other Property Use" were selected in this report, since they are more conservative than the values for other soil uses. The groundwater criteria were derived from the Provincial Groundwater Monitoring Information System (PGMIS) and from groundwater well surveillance data.

6) Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario (MOEE 1993)
Applicable to sediment criteria

These guidelines replace the ministry's sediment quality guidelines from 1976. They are divided into three levels of effect: No Effect Level (NEL) (where no contaminants are passed through the food chain), Lowest Effect Level (LEL) (where the majority of benthic organisms are unaffected), and Severe Effect Level (SEL) (where disturbances of the benthic community can be expected). Because there are no NEL values listed for any chemical elements, the LEL values are cited from this report. However, none of the guidelines were adopted as acceptance criteria since they were not the minima among the secondary reference benchmarks and were not applicable as less restrictive alternatives to the minimum benchmarks.

7) Provincial Water Quality Objectives (MOEE 1994)
Applicable to surface water and groundwater criteria

The Provincial Water Quality Objectives (PWQO) are numerical and narrative ambient surface water quality objectives set by the Province of Ontario that protect aquatic life, public health and aesthetic features. Criteria cited in this report correspond to the PWQO/Interim PWQO.

8) Ontario's Ambient Air Quality Criteria (OMECP 2020)
Applicable to air criteria

The Ambient Air Quality Criteria (AAQC) protect against adverse effects on human health or the environment. They are reflective of general air quality, independent of source or receptor location, and are commonly used in environmental assessments. AACQs are listed for both compounds and elements; only the elemental data was cited from this report.

4.3 Tier 3: Tertiary References

The tertiary references are used to supplement the primary and secondary references. They are published by reputable institutions and are peer-reviewed, lending them the credibility to be cited herein. While many reputable references are available internationally (for example, guidelines from the World Health Organization and the United States Environmental Protection Agency) only a few provide a supplement to the criteria that are unavailable in the primary references. Benchmarks from other Canadian provinces (i.e., not Ontario) are included within the tertiary references.

It is noted that while GA (2018), Suter and Tsao (1996), Sample et al. (1996) and Efroymson (1997b) are listed below as tertiary references, benchmarks from these four references were not adopted as acceptance criteria after application of the methodology described in Section 3 (i.e., their benchmarks were not the minima among those of the tertiary references and were not applicable as less restrictive alternatives to the minimum benchmarks).

1) **Environmental Quality Guidelines for Alberta Surface Waters (GA 2018)**
   Applicable to surface water criteria

   This document updates and expands surface water and aquatic ecosystem guidelines for Alberta. It is the most recent edition in an ongoing process of development and updates of environmental quality guidelines. However, none of the guidelines were adopted as acceptance criteria since they were not the minima among the tertiary reference benchmarks and were not applicable as less restrictive alternatives to the minimum benchmarks.

2) **Database of Environmental Quality Guidelines (ECCC 2016)**
   Applicable to surface water, groundwater, soil, sediment and air criteria

   A database of guidelines for chemicals in various media from multiple national and international jurisdictions was developed to facilitate screening and remediation processes for federal contaminated sites. Note that this reference is classified as a Tertiary Reference because only guidelines/standards from other provinces or international jurisdiction are used in this report (i.e., all Federal Canadian and Provincial Ontario guidelines) are already considered as Primary or Secondary References.

3) **Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants (Efroymson 1997a)**
   Applicable to soil criteria

   This document, prepared for the U.S. Department of Energy, presents a standard method for deriving benchmarks or the purpose of screening contaminants to determine which of them are worthy of further consideration as contaminants of potential concern. It presents a set of data concerning effects of chemicals in soil or soil solution on plants, and a set of phytotoxicity benchmarks for 38 chemicals potentially associated with United States Department of Energy (DOE) sites.

4) Toxicological Benchmarks for Contaminants of Potential Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Processes (Efroymson 1997b)
Applicable to soil criteria

This document, prepared for the U.S. Department of Energy, presents a standard method for deriving benchmarks or the purpose of screening contaminants to determine which of them are worthy of further consideration as contaminants of potential concern. It presents a set of data concerning effects of chemicals in soil on invertebrates and soil microbial processes, and benchmarks for chemicals potentially associated with United States Department of Energy sites. This document was included in the survey of criteria, but no resulting. However, none of the benchmarks were adopted as acceptance criteria since they were not the minima among the tertiary reference benchmarks and were not applicable as less restrictive alternatives to the minimum benchmarks.

5) Protective Action Criteria for Chemicals (EMI SIG 2016)
Applicable to air criteria

The Protective Action Criteria (PAC) are published by the Emergency Management Issues Special Interest Group (EMI SIG), which is sponsored by the United States Department of Energy Office of Emergency Management and Policy. The PAC are intended to provide the information necessary to take the proper corrective action in the event of an uncontrolled release of hazardous chemicals and aid in the planning of effective emergency responses. There are three common benchmark values for each chemical (i.e., PAC-1, -2, and -3), each successive benchmark associated with an increasingly severe effect that involves a higher level of exposure. PAC-1 values are the most conservative and are thus quoted from this report (EMI SIG 2016).

6) Supplementary Non-Radiological Interim Acceptance Criteria for the Protection of Persons and the Environment (Fernandes et al. 2019)

This report contains derived benchmarks for a subset of elements missing from the previous literature/guidance review of APM program interim acceptance criteria (i.e., Au, Bi, Br, I, In, Ir, Os, Pa, Pt, Rh, Ru, Tl and W) (Medri 2015). These elements did not have clear jurisdictional criteria in the various compilations. Criteria were derived based on toxicity compiled from a literature search and applied with surrogate approaches and uncertainty factors. New toxicity data for Ru and Rh was commissioned and included.

7) Ecological Screening Values for Surface Water, Sediment and Soil: 2005 Update (Friday 2005)
Applicable to surface water, sediment and soil criteria

This report provides a comprehensive listing of ecological screening values for surface water, sediment and soil, which are used to support ecological risk assessments for the remediation program at the Savannah River Site.

8) Guidance for Ecological Risk Assessments (ODEQ 1998)
Applicable to soil and surface water

This report, published by the Oregon Department of Environmental Quality, presents guidance criteria to be used in environmental risk assessments. It is useful because it provides comprehensive coverage. The criteria are heavily populated by benchmarks set by

Oak Ridge National Laboratory (ORNL). They are organized into four different assessment levels, from Level 1 (scoping) to Level IV (field baseline). The Level II (screening) criteria are cited from this report, since they are the most conservative (the Level I criteria are non-numerical). They are developed for soil and surface water for the protection of plants, invertebrates, terrestrial birds and mammals, aquatic birds and mammals, and other aquatic biota. ODEQ (1998) presents freshwater and marine (saltwater) values; but only the freshwater values are cited from this report since the repository will not be sited near saltwater.

9) **Conducting Ecological Risk Assessments, September 2020 (ODEQ 2020)**
Applicable to soil and sediment criteria

The document provides the process framework and methods to be used for ecological risk assessments at cleanup sites in Oregon. It provides Risk-Based Concentrations, which are receptor and media specific concentrations that represent acceptable risk to plants, invertebrates, fish, birds and mammals within terrestrial and aquatic environments. This document supersedes ODEQ (1998).

10) **Toxicological Benchmarks for Wildlife: 1996 Revision (Sample et al. 1996)**
Applicable to surface water and soil criteria

This report, prepared for the United States Department of Energy by the Oak Ridge National Laboratory, presents toxicological benchmarks for assessment of effects of certain chemicals on mammalian and avian wildlife species. The benchmarks are intended for use in screening assessments. However, none of the benchmarks were adopted as acceptance criteria since they were not the minima among the tertiary reference benchmarks and were not applicable as less restrictive alternatives to the minimum benchmarks.

11) **Maximum Permissible Concentrations and Negligible Concentrations for Rare Earth Elements (Sneller et al. 2000)**
Applicable to surface water, sediment and soil

This report, published by the Netherlands' National Institute of Public Health and the Environment, contains Maximum Permissible Concentrations (MPCs) and Negligible Concentrations for water, soil and sediment for rare earth elements. The MPC for naturally occurring substances is defined as the sum of the Maximum Permissible Addition (MPA), which can be calculated using data on ecotoxicology and environmental, and the background concentration. The MPCs, which are derived, are a benchmark of the potential risks to ecosystems. Sneller et al. (2000) presents freshwater and saltwater MPC values; but only the freshwater values are cited from this report since it is not anticipated that the repository will be sited near saltwater.

12) **Toxicological Benchmarks for Screening Contaminants of Concern for Effects on Aquatic Biota (Suter and Tsao 1996)**
Applicable to surface water and groundwater

This report, prepared for the United States Department of Energy by the Oak Ridge National Laboratory, presents toxicological benchmarks in water for screening aquatic ecological effects. However, none of the benchmarks were adopted as acceptance criteria since they were not the minima among the tertiary reference benchmarks and were not applicable as less restrictive alternatives to the minimum benchmarks.

13) Toxicity Factors Database (TCEQ 2016)
Applicable to air criteria

The Toxicity Factor Database is part of the Texas Air Monitoring Information System. It contains the Effects Screening Levels (ESLs), which provides the benchmark for excluding airborne contaminants from further consideration. They are not to be used as ambient air standards for air monitoring.

14) Derivation and Use of Sediment Quality Guidelines for Ecological Risk Assessment of Metals and Radionuclides Released to the Environment from Uranium Mining and Milling Activities in Canada (Thompson et al. 2005)
Applicable to sediment criteria

This journal article, published in Environmental Monitoring and Assessment journal, presents the Lowest Effect Level (LEL) and Severe Effect Level (SEL) concentrations for nine metals and three radionuclides released to the environment during mining and milling of uranium ore. It uses historical and current data collected for diverse purposes in the uranium and milling regions of Canada.

4.4 Tier 4: Surrogates

A surrogate approach was applied for element/media combinations for which criteria were not identified in the primary, secondary or tertiary references, as described in Table 3-1. Table 4-1 describes following surrogates that were applied:

Table 4-1: Summary of Surrogates

Surrogate Methods	Elements	Medium	Acceptance Criteria
1. Use of surface water criteria to derive groundwater criteria	La	Groundwater	10X surface water criterion for La
	Nd	Groundwater	10X surface water criterion for Nd
	Sn	Groundwater	10X surface water criterion for Sn
2. Interchange of soil and sediment criteria	Cs*	Sediment	Soil criterion for Li
	Rb*	Sediment	Soil criterion for Li
	Zr	Sediment	Soil criterion for Zr
	Nd	Soil	Sediment criteria for Nd
3. Use of acute benchmarks in air	Cs*	Air	Li benchmarks for acute exposures
	La	Air	La benchmarks for acute exposure
	Nd	Air	Nd benchmarks for acute exposure
4. Chemical Analogues	Cs*	All media	Benchmark for Li, an alkali metal in the same group (column)
	Rb*	All media except air	Benchmark for Li, an alkali metal in the same group (column)

*Cs in sediment and Rb in sediment combines surrogate methods 2 and 4, and Cs in air combines surrogate methods 3 and 4.

Surrogates are also identified and described in Table 5-2.

5. PROPOSED ACCEPTANCE CRITERIA

This document presents the basis for proposed acceptance criteria to be used as reference values to assess the impact of the APM DGR project on human health and the environment from the potential release of non-radiological contaminants in post-closure safety assessments.

Acceptance criteria are shown in Table 5-1 for the 17 elements of interest for post-closure safety assessments, with details about the source benchmarks and references shown in Table 5-2. These tables are coloured according to the tiers from which the acceptance criteria were sourced, with Tier 1 having the most certainty and Tier 4 having the least certainty. A summary of benchmarks from all references is shown in Appendix A.

As described in Table 3-1, most acceptance criteria were selected to correspond to the minimum criteria identified in their respective applicable references. For Cd and Pb in surface water, the criteria were selected to correspond to the CCME guidelines for the protection of aquatic life (CCME (2021d), applicable to a range of water hardness (i.e., concentration of $CaCO_3$).

Table 5-1: Proposed Post-Closure Non-Radiological Acceptance Criteria

Element	Surface Water (µg/L)	Groundwater (µg/L)	Soil (µg/g)	Sediment (µg/g)	Air (µg/m³)
Ag	0.25	0.1	20	0.5	0.01
Ba	1000	500	500	20	0.5
Cd	=0.04 µg/L if [$CaCO_3$] <17 mg/L =$10^{\{0.83(\log[\text{hardness}])-2.46\}}$ µg/L if [$CaCO_3$] is ≥ 17mg/L and ≤280 mg/L =0.37 µg/L if $CaCO_3$ is >280 mg/L	5.1	1.4	0.6	0.005
Cr	1	4.9	0.34	37	0.00007
Cs	2500	2500	2	2	19
Hg	0.004	3	6.6	0.17	0.025
La	0.04	0.4	50	4700	100
Mo	10	10	5	3	3
Nd	1.8	18	7500	7500	100
Pb	=1 µg/L if [$CaCO_3$] <60 mg/L =$e^{\{1.273[\ln(\text{hardness})]-4.705\}}$ µg/L if [$CaCO_3$] is ≥60 mg/L and ≤180 mg/L =7 µg/L if CaCO3 is > 180 mg/L	100	70	35	0.2
Pd	0.068	0.68	0.012	4.1	5
Rb	2500	2500	2	2	2.5
Rh	10	10	2.2	600	0.1
Ru	10	100	1	390	3
Sn	25	250	5	900	2
U	10	10	23	32	0.03
Zr	4	4	97	97	5

Legend	Tier 1: Primary References	Tier 2: Secondary References	Tier 3: Tertiary References	Tier 4: Surrogates

Table 5-2: References for Table 5-1

	Surface Water (µg/L)	Groundwater (µg/L)	Soil (µg/g)	Sediment (µg/g)	Air (µg/m^3)
Ag	CCME (2021d) - Water Quality Guidelines for the Protection of Aquatic Life, Long-term	GC (2012) - Tier I and Tier 2 Federal Interim Groundwater Quality Objective. MOEE (1994) - Provincial Water Quality Objective	CCME (2021b) - Soil Quality Guidelines for the Protection of Environmental and Human Health (Agricultural and Residential/parkland soils)	MOE (2011) - Full Depth Background Site Condition Standard. All types of property uses.	TCEQ (2016) - Screening value
Ba	GO (2018). Ontario Drinking Water Standards	MOE (2011) - Full Depth Background Site Condition Standard. All types of property uses.	CCME (2021b) - Soil Quality Guidelines for the Protection of Environmental and Human Health (Residential/parkland soils)	Friday (2005) - Screening Value	TCEQ (2016) - Screening value
Cd	CCME (2021d) - Water Protection Guideline for the Protection of Aquatic Life, Long-term value.	CCME (2021c) - Water Quality Guideline for the Protection of Agriculture (Irrigation)	CCME (2021b) - Soil Quality Guidelines for the Protection of Environmental and Human Health (Agricultural)	CCME (2021a) - Interim Sediment Quality Guideline for the Protection of Aquatic Life	OMECP (2020) - Standard for cadmium and cadmium compounds
Cr	CCME (2021d) - Water Quality Guidelines for the Protection of Aquatic Life, Long Term. Value for hexavalent chromium used. Value for trivalent chromium is 8.9 ug/L	CCME (2021c) - Water Quality Guidelines for the Protection of Agriculture (Livestock). Value for hexavalent chromium.	ODEQ (2020) - Risk Based Concentration	CCME (2021a) - Interim Sediment Quality Guideline for the Protection of Aquatic Life. Value for total chromium.	OMECP (2020) - Standard. Value for chromium compounds, hexavalent form.
Cs	Surrogate - Assumed equivalent to Li criterion, an Alkali metal in the same group (column). Li benchmark is from CCME (2021c)- Water Quality Guidelines for the Protection of Agriculture	Surrogate - Assumed equivalent to Li criterion, an Alkali metal in the same group (column). Li benchmark is from CCME (2021c)- Water Quality Guidelines for the Protection of Agriculture	Surrogate - Assumed equivalent to Li, an alkali metal in the same group (column). Li value from Efroymson et al. (1997a), ODEQ (1998), Friday (2005). Screening value.	Surrogate - Assumed equivalent to Li criterion for soil. Li is an Alkali metal in the same group (column)	Surrogate - Value for acute exposures. Acute value based on EMISIG (2016) - Protective Action Criteria from EMI SIG (2016) divided by 300, the median ratio between the EMI SIG (2016) benchmarks (which are intended for emergency use and are significantly higher than other benchmarks) and known benchmarks from secondary references.
Hg	CCME (2021d) - Water Quality Guidelines for the Protection of Aquatic Life. Value for methyl mercury.	CCME (2021c) - Water Quality Guidelines for the Protection of Agriculture (Livestock)	CCME (2021b) - Soil Quality Guidelines for the Protection of Environmental and Human Health (Agricultural and residential/parkland).	CCME (2021a) - Interim Sediment Quality Guideline for the Protection of Aquatic Life.	TCEQ (2016) - Screening value.
La	ECCC (2016) - Protective of Aquatic Life. Corresponds to 5th percentile of EC50 with lifetime exposure/non-lethal endpoints as reported in US EPA 2009.	Surrogate Applied dilution factor of 10 to surface water criterion. Assumed non-toxic to humans.	Efroymson et al. (1997a), ODEQ (1998), Friday (2005). Screening value.	Sneller et al. (2000) - Maximum Permissible Concentration	Surrogate - Value for acute exposures. Acute value based on EMISIG (2016) - Protective Action Criteria from EMI SIG (2016) divided by 300, the median ratio between the EMI SIG (2016) benchmarks (which

	Surface Water (µg/L)	Groundwater (µg/L)	Soil (µg/g)	Sediment (µg/g)	Air (µg/m^3)
					are intended for emergency use and are significantly higher than other benchmarks) and known benchmarks from secondary references.
Mo	CCME (2021c) - Water Quality Guidelines for the Protection of Agriculture	CCME (2021c) - Water Quality Guideline for the Protection of Agriculture (Irrigation).	CCME (2021b) - Soil Quality Guidelines for the Protection of Environmental and Human Health (Agricultural)	Friday (2005) - Screening Value	TCEQ (2016) - Screening value.
Nd	Sneller et al. (2000) - Maximum Permissible Concentration	Surrogate – Applied dilution factor of 10 to surface water criterion. Assumed non-toxic to humans.	Surrogate: Same as sediment criterion	Sneller et al. (2000) - Maximum Permissible Concentration	Surrogate - Value for acute exposures. Acute value based on EMISIG (2016) - Protective Action Criteria from EMI SIG (2016) divided by 300, the median ratio between the EMI SIG (2016) benchmarks (which are intended for emergency use and are significantly higher than other benchmarks) and known benchmarks from secondary references.
Pb	CCME (2021d) - Water Quality Guidelines for the Protection of Aquatic Biota.	CCME (2021c) - Water Quality Guideline for the Protection of Agriculture (Livestock)	CCME (2021b) - Soil Quality Guidelines for the Protection of Environmental and Human Health (Agricultural)	CCME (2021a) - Interim Sediment Quality Guideline for the Protection of Aquatic Life.	OMECP (2020) - Standard for lead and lead compounds
Pd	Fernandes et al. (2019) - Derived using toxicity data	Fernandes et al. (2019) - Based on ECHA PNEC	Fernandes et al. (2019). Based on ECHA PNEC.	Fernandes et al. (2019) - Derived using literature Kd	TCEQ (2016) - Screening value.
Rb	Surrogate - Assumed equivalent to Li criterion, an Alkali metal in the same group (column). Li benchmark is from CCME (2021c)- Water Quality Guidelines for the Protection of Agriculture	Surrogate - Assumed equivalent to Li criterion, an Alkali metal in the same group (column). Li benchmark is from CCME (2021c)- Water Quality Guidelines for the Protection of Agriculture	Surrogate - Assumed equivalent to Li, an alkali metal in the same group (column). Li value from Efroymson et al. (1997a), ODEQ (1998), Friday (2005). Screening value.	Surrogate - Assumed equivalent to Li criterion for soil. Li is an Alkali metal in the same group (column)	TCEQ (2016) - Screening value
Rh	Fernandes et al. (2019) - Derived using toxicity data	Fernandes et al. (2019) - Derived using toxicity data	Fernandes et al. (2019) - Derived using toxicity data	Fernandes et al. (2019) - Derived using literature Kd	TCEQ (2016) - Screening value
Ru	Fernandes et al. (2019) - Derived using toxicity data	Fernandes et al. (2019) - Derived using toxicity data	Fernandes et al. (2019) - Derived using toxicity data	Fernandes et al. (2019) - Derived using literature Kd	TCEQ (2016) - Screening value
Sn	ECCC (2016). Originally from UK Environment Agency. Applies to dissolved solution. NOEC or 5th percentile of SSD (depending on data availability) with appropriate uncertainty factor	Surrogate – Applied dilution factor of 10 to surface water criterion. Assumed non-toxic to humans.	CCME (2021b) - Soil Quality Guidelines for the Protection of Environmental and Human Health (agricultural)	Friday (2005) - Screening Value	TCEQ (2016) - Screening value
U	CCME (2021c) - Water Quality	CCME (2021c) - Water Quality	CCME (2021b) - Soil Quality	Thompson et al. (2005) -	GO (2021) and OMECP (2020)

	Surface Water (µg/L)	Groundwater (µg/L)	Soil (µg/g)	Sediment (µg/g)	Air (µg/m^3)
	Guidelines for the Protection of Agriculture (Irrigation)	Guideline for the Protection of Agriculture (Irrigation)	Guidelines for the Protection of Environmental and Human Health (agricultural and residential/parkland)	Lowest Effect Level	- Standard for uranium and uranium compounds
Zr	MOEE (1994) - Interim Provincial Water Quality Objective	MOEE (1994) - Interim Provincial Water Quality Objectives	ODEQ (1998) - Screening value	Surrogate: Same as soil criterion	TCEQ (2016) - Screening value

Legend	Primary References	Secondary References	Tertiary References	Surrogate

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APPENDIX A: BENCHMARKS FROM PRIMARY, SECONDARY AND TERTIARY REFERENCES

This appendix contains summary tables of guidelines, standards and benchmarks from the primary, secondary and tertiary references. Minimum guidelines are reported when multiple different types of guidelines are offered in the references, as described in Table 3-1 (e.g., in the case of different species, different protective endpoints, compounds, etc.).

Table A- 1: Available Guidelines, Benchmarks and Standards for Surface Water (µg/L)

	Primary	Secondary			Tertiary							
	CCME (2021c, d)	HC (2020)	MOEE (1994)	GO (2018)	Fernandes et al. (2019)	GA (2018)	ECCC (2016)	ODEQ (1998)	Sneller et al. (2000)	Sample et al. (1996)	Friday (2005)	Suter and Tsao (1996)
Ag	0.25	-	0.1	-	-	-	-	0.12	-	-	0.012	-
Ba	-	2000	-	1000	-	-	-	4	-	-	3.9	4
Cd	0.04	7	0.1	5	-	-	-	2.2	-	-	0.017	1.1
Cr	1	500	1	50	-	-	-	-	-	-	1	11
Cs	-	-	-	-	-	-	-	-	-	-	-	-
Hg	0.004	1	0.2	1	-	-	-	0.77	-	5	0.003	0.0028
La	-	-	-	-	-	-	0.04	-	10.1	-	-	-
Mo	10	-	40	-	-	-	-	370	-	-	73	370
Nd	-	-	-	-	-	-	-	-	1.8	-	-	-
Pb	1	5	1	10	-	-	-	2.5	-	69	1	3.2
Pd	-	-	-	-	0.068	-	-	-	-	-	-	-
Rb	-	-	-	-	-	-	-	-	-	-	-	-
Rh	-	-	-	-	10	-	-	-	-	-	-	-
Ru	-	-	-	-	10	-	-	-	-	-	-	-
Sn	-	-	-	-	-	-	25	73	-	-	73	73
U	10	20	5	20	-	-	-	2.6	-	-	2.6	2.6
Zr	-	-	4	-	-	-	4	17	-	-	17	17

Table A- 2: Available Guidelines, Benchmarks and Standards for Groundwater (µg/L)

Element	Primary	Secondary					Tertiary
	CCME (2021c)	GC (2012)	HC (2020)	MOE (2011)	MOEE (1994)	GO (2018)	Fernandes et al. (2019)
Ag	-	0.1	-	0.3	0.1	-	-
Ba	-	500	2000	610	-	1000	-
Cd	5.1	0.017	7	0.5	0.1	5	-
Cr	4.9	-	500	-	1	50	-
Cs	-	-	-	-	-	-	-
Hg	3	0.026	1	0.1	0.2	1	-
La	-	-	-	-	-	-	-
Mo	10	73	-	23	40	-	-
Nd	-	-	-	-	-	-	-
Pb	100	100	5	1.9	1	10	-
Pd	-	-	-	-	-	-	0.68
Rb	-	-	-	-	-	-	-
Rh	-	-	-	-	-	-	10
Ru	-	-	-	-	-	-	100
Sn	-	-	-	-	-	-	-
U	10	10	20	8.9	5	20	-
Zr	-	-	-	-	4	-	-

Table A- 3: Available Guidelines, Benchmarks and Standards for Soil (µg/g)

Element	Primary	Secondary	Tertiary						
	CCME (2021b)	MOE (2011)	Efroymson et al. (1997a,b)	Fernandes et al. (2019)	ECCC (2016)	ODEQ (1998)	ODEQ (2020	Sample et al. (1996)	Friday (2005)
Ag	20	0.5	2	-	-	2	2.6	-	2
Ba	500	210	500	-	-	638	110	-	160
Cd	1.4	1	4	-	-	4	0.27	-	0.38
Cr	-	-	0.4	-	0.38	-	0.34	-	0.4
Cs	-	-	-	-	-	-	-	-	-
Hg	6.6	0.16	0.1	-	-	0.0032	0.00035	0.71	0.67
La	-	-	50	-	50	50	-	-	50
Mo	5	2	2	-	-	2	2.6	-	2
Nd	-	-	-	-	-	-	-	-	-
Pb	70	45	50	-	-	16	11	18.8	16
Pd	-	-	-	0.012	-	-	-	-	-
Rb	-	-	-	-	-	-	-	-	-
Rh	--	-	-	2.2	-	-	-	-	-
Ru	-	-	-	1	-	-	-	-	-
Sn	5	-	50	-	-	50	-	-	20
U	23	1.9	5	-	-	5	25	-	5
Zr	-	-	-	-	-	97	-	-	-

Table A- 4: Available Guidelines, Benchmarks and Standards for Sediment (µg/g)

Element	Primary	Secondary		Tertiary					
	CCME (2021a)	MOE (2011)	MOEE (1993)	Fernandes et al. (2019)	ECCC (2016)	ODEQ (2020)	Sneller et al. (2000)	Friday (2005)	Thompson et al. (2005)
Ag	-	0.5	-	-	-	4.5	-	0.73	-
Ba	-	-	-	-	29	-	-	20	-
Cd	0.6	0.6	0.6	-	-	0.6	-	0.6	-
Cr	37.3	-	26	-	-	37	-	36	36.7
Cs	-	-	-	-	-	-	-	-	-
Hg	0.17	0.2	0.2	-	-	0.2	-	0.13	-
La	-	-	-	-	-	-	4700	-	-
Mo	-	-	-	-	25	-	-	3	8.3
Nd	-	-	-	-	-	-	7500	-	-
Pb	35	31	31	-	-	35	-	30.2	27.7
Pd	-	-	-	4.1	-	-	-	-	-
Rb	-	-	-	-	-	-	-	-	-
Rh	-	-	-	600	-	-	-	-	-
Ru	-	-	-	390	-	-	-	-	-
Sn	-	-	-	-	-	-	-	900	-
U	-	-	-	-	-	-	-	-	32
Zr	-	-	-	-	-	-	-	-	-

Table A- 5: Available Guidelines, Benchmarks and Standards for Air (µg/m^3)

Elements	Secondary		Tertiary			
	GO (2021)	OMECP (2020)	Fernandes et al. (2019)	ECCC (2016)	EMISIG (2016)*	TCEQ (2016)
Ag	-	-	-	-	1	0.01
Ba	-	-	-	1	5	0.5
Cd	-	0.005	-	-	0.33	0.0033
Cr	0.00014	0.00007	-	-	5	-
Cs	-	-	-	-	19	-
Hg	-	-	-	-	0.11	0.025
La	-	-	-	-	100	-
Mo	-	-	-	-	100	3
Nd	-	-	-	-	100	-
Pb	-	0.2	-	-	0.5	-
Pd	-	-	5	-	20	5
Rb	-	-	-	-	13	2.5
Rh	-	-	0.1	-	10	0.1
Ru	-	-	3	-	100	3
Sn	-	-	-	-	20	2
U	0.03	0.03	-	-	2	0.2
Zr	-	-	-	-	33	5

*EMI SIG (2016) values are intended for short-term (1 hour) emergency use and are significantly higher than similar benchmarks from other references. As such, the values presented in this table and used as a basis for screening criteria are divided by 300, the median ration between EMI SIG (2016) values and known acute benchmarks from secondary references.