Non-Radiological Interim Acceptance Criteria for the Protection of Persons and the Environment

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Nuclear Waste Management Organization

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ABSTRACT

Title: **Non-Radiological Interim Acceptance Criteria for the Protection of Persons and the Environment**
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Abstract

The purpose of this report is to present interim acceptance criteria for the protection of persons and the environment from non-radiological releases (i.e., potentially hazardous chemical elements) from a used fuel deep geological repository. The criteria are based on Canadian Federal and 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. The criteria are cautiously realistic (i.e., they ensure the protection of persons and the environment without being excessively conservative).

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1. INTRODUCTION

This document presents the interim acceptance criteria for the protection of persons and the environment from the postclosure non-radiological releases (i.e., potentially hazardous chemical elements) from a used fuel deep geological repository. These criteria are to be used as reference values to assess the acceptability of the impact of the repository on human health and the environment. They are based on Canadian Federal and Provincial guidelines, supplemented as required by international guidelines. They have been assembled taking into account the guidance of G-320 (CNSC, 2006).

In the Canadian context, five major postclosure safety assessments have been completed to examine the safety implications of a hypothetical deep geological repository for used fuel, each considering variations in repository design and site characteristics. Due to the radiological hazard of the used fuel, the main emphasis of these safety assessments was on the radiological consequences. However, because a repository contains a variety of other materials, some of which are chemically toxic in large enough quantities, analyses of non-radiological consequences have also been included in these safety assessments.

There is no single authoritative reference with criteria for all relevant elements. Criteria for evaluating the chemical toxicity of chemical elements released from a used fuel repository were originally developed for the Atomic Energy of Canada Limited (AECL) Environmental Impact Statement case study (AECL, 1994; Goodwin and Mehta, 1994). They were revised for the Horizontal Borehole Concept Case Study (Garisto et al. 2005) for three environmental media (water, soil and air). The criteria were based on Canadian Federal and Provincial guidelines, international guidelines, peer-reviewed reports, as well as values derived from chemotoxicity data for rats and mice. With the addition of a sediment medium and the differentiation between surface water and groundwater media, these criteria were updated for use in the subsequent postclosure safety assessments for hypothetical sites in sedimentary (NWMO, 2013) and crystalline (NWMO, 2012) rock environments. The current report presents a comprehensive set of interim acceptance criteria for all relevant elements in a used fuel repository. It documents the basis for the proposed interim acceptance criteria for five environmental media: groundwater, surface water, soil, sediment and air.

These criteria are generally similar to the criteria accepted by the Canadian Nuclear Safety Commission (CNSC) for Ontario Power Generation's proposed Deep Geologic Repository (DGR) for Low and Intermediate Level Waste (Quintessa et al. 2011). The main differences are that the DGR criteria emphasized the official Ontario standards (e.g., MOE 2011), and that they covered a smaller number of elements relevant to low and intermediate level waste.

The interim acceptance criteria are intended to be cautiously realistic; that is, they ensure the protection of all forms of life (animals, plants and humans) without being excessively conservative. These criteria are intended for postclosure conditions in that they are selected for chronic exposure conditions, and are relevant postclosure elements and species. They are "interim" acceptance criteria because they have not been formally approved for use in a used fuel repository licence application.

2. SAFETY ASSESSMENT APPROACH

Postclosure safety assessments evaluate the potential environmental media concentrations of materials that could be released from a repository. According to G-320 (CNSC, 2006), both Normal Evolution Scenarios and Disruptive Scenarios are to be considered in postclosure safety assessments.

The Normal Evolution Scenario is based on a reasonable extrapolation of present day site features and receptor lifestyles. It includes the expected evolution of the site postclosure and degradation of the waste disposal system as it ages. Depending on site-specific conditions and the timeframe of the assessment, the Normal Evolution Scenario could include extreme conditions such as climate shifts or the onset of glaciations. Similarly, periodic natural events such as floods or forest fires could also be considered within this event category. Disruptive Scenarios postulate the occurrence of very unlikely events leading to possible penetration of the repository and/or abnormal loss of containment.

The interim acceptance criteria described in this report are reference values to assess the impact of the repository on human health and the environment from non-radiological releases estimated by these postclosure safety assessments. For an appropriately sited and designed repository, the expected environmental media concentrations would be less than these criteria.

Exceedance of one of these criteria does not necessarily indicate unacceptable risk. As appropriate, consideration may be given to assessing the conservatism in the interim acceptance criterion through reference to the original sources as identified here, to use of less conservative release and exposure models, to the likelihood and nature of the exposure, and to mitigation measures. Furthermore, the use of criteria in exclusion of other information (such as background concentrations of naturally occurring substances) may lead to erroneous conclusions or predictions of media quality.

Indeed, a difficulty in evaluating the potential for harm from releases to a hypothetical site is that the background concentrations are unknown. Consequently, it is not known whether the releases from the repository contribute to background concentrations that are far below the interim acceptance criteria, or whether they contribute to background concentrations that are already at or above the interim acceptance criteria. A further difficulty is that since some of the interim acceptance criteria are based on upper limits of background concentrations rather than on chemical effects data, the natural background concentrations might be expected to exceed criteria in some instances. This complicates the interpretation of the criteria use.

For the preliminary safety assessment of a hypothetical site, or for a site where the natural background concentrations are not yet known, the media concentrations will be compared directly to the interim acceptance criteria, thereby implicitly assuming zero (or very low) background concentrations. However, the method for determining the acceptability of chemical releases to real sites would be described in the site specific safety assessment. If background concentrations for some potential contaminants are very close to, or already exceed criteria at a real site, consultations and agreement with the regulator on an acceptable approach would be required. The criteria must be environmentally protective and scientifically defensible.

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 take into account 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 CRITERIA

This report does not present new field data or original criteria calculations. Rather, the criteria are taken from existing Canadian Federal and Provincial guidelines and publications (termed the “primary references”), supplemented as required with internationally developed guidelines (termed the “secondary references”). All references are described in Section 5.

The primary and secondary references are used to generate two sets of criteria. The first set (the minimum criteria) represents the lowest possible criteria from the available primary references, supplemented as required by the secondary references. The lowest possible criteria are selected irrespective of the conditions under which they are meant to be applied (i.e., the lowest value of a range is selected irrespective of the conditions specified by the range), irrespective of the relevant speciation of the element (i.e., the lowest value of all forms of chromium is selected). The minimum criteria are conservative and potentially impracticable for some elements even in the natural state, but can be used as screening criteria. They are described in Section 6.

The second set of criteria (the interim acceptance criteria) is selected using the minimum criteria as a basis, except that conditions under which they are meant to be applied are taken into account. For example, in CCME (2014d), the criterion for copper in surface waters depends on the concentration of calcium carbonate, which ought to be considered when assessing the acceptability of the copper concentration. The interim acceptance criteria are considered to be cautiously realistic and appropriate for use as a standard of protection for humans and the environment. They are described in Section 7.

Generally, chemical speciation is relevant to assessment of these criteria. However this is handled differently in the various references. Where guidelines are presented for separate species (e.g. trivalent or hexavalent chromium), the lowest criteria of all relevant species is adopted here.

The criteria defined for each environmental media protect the following:

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).

4. SELECTION OF ELEMENTS

Criteria are presented for all elements in the periodic table, with the exception of the elements identified in Table 4-1 and the elements for which criteria do no exist. Chemical compounds that are likely to form in the postclosure phase of the repository are considered implicitly by the criteria for their dominant elements (for example, in some cases the criterion for mercury is actually the criterion for methyl mercury, since methyl mercury is more limiting than elemental mercury). Chemical compounds that are implicitly considered are discussed in Appendix A. Criteria that are bound by chemical compounds rather than chemical elements are identified in Sections 6, 7 and 8.

Table 4-1: Excluded Chemical Elements

Category	Reason	Chemical Elements
Common or Essential Elements	Essential to life and abundant.	C, H, N, O
Inert Gases	Do not react chemically.	Ar, He, Kr, Ne Rn and Xe
Actinide Elements [a]	All isotopes of each of these elements are radioactive; chemical toxicity values are not defined and it is assumed that toxicity is sufficiently addressed through radiotoxicity.	Ac, Am, Bk, Cf, Cm, Es, Fm, Lr, Md, No, Np, Pa, Pu and Th
Transactinide Elements	Man-made; exist for less than a second.	Bh, Cn, Db, Ds, Fl, Hs, Lv, Mt, Rf, Rg and Sg

a Uranium is included in the assessment because it is a special actinide for which the chemotoxicity exceeds the radiotoxicity. Thus, it does not appear in the list of excluded chemical elements.

Environmental media chemical criteria do not exist for At, Au, Cs, Er, Fr, Ga, Ge, In, Ir, Os, Pd, Pm, Po, Ra, Re, Rb, Rh, Ru, Si and Yb. The potential importance of these elements in a safety assessment would need to be assessed, potentially based on their abundance in the waste and in environmental media.

5. SOURCES OF CRITERIA

As described in Section 3, criteria are preferentially selected from the primary references and supplemented by secondary references as required. Below is a description of the primary and secondary references.

5.1 PRIMARY REFERENCES

The primary references are Provincial and Federal Canadian guidelines and publications. These references are termed primary because they are directly relevant to Canadian protection standards, and take priority over guidelines developed internationally.

5.1.1 Federal Canadian Guidelines and Publications

A. The Canadian Environmental Quality Guidelines

The Canadian Environmental Quality Guidelines, published by the Canadian Council of Ministers of the Environment (CCME), 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 below.

A.1 The Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health (CCME, 2014b)

These guidelines are derived for the protection of ecological receptors in the environment and for the protection of 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.

A.2 Canadian Water Quality Guidelines for the Protection of Agricultural Water Uses (CCME, 2014c)

These guidelines are for the protection of 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.

A.3 The Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME, 2014d)

These guidelines are for the protection of 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 from this report, since it is not anticipated that the repository will be sited near saltwater.

A.4 The Canadian Sediment Quality Guidelines for the Protection of Aquatic Life (CCME, 2014a)

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.

A.5 Air Quality Guidelines for the Protection of Human Health and the Environment

The CCME guidelines for air are limited to particulates, SO_2, NO_2, HF and CO. Therefore, they are not used in this report.

B. Guidelines for Canadian Drinking Water Quality (HC, 2012)

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. These guidelines are prepared with the specific intent of protecting the most vulnerable members of society (children and the elderly). 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 used as groundwater criteria.

C. 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)

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.

5.1.2 Provincial Guidelines and Publications

At the time of publication of this report, communities from two Canadian provinces were involved in the process for selecting a site for a used fuel repository: Ontario and Saskatchewan. Therefore, guidelines from these two provinces are considered. However, because the Saskatchewan Environmental Quality Guidelines are only available in draft form, only Ontario guidelines are considered at this time. Below is a description of the available Ontario guidelines.

A. Provincial Water Quality Objectives (MOEE, 1994)

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.

B. Soil, Groundwater and Sediment Standards for use under Part XV.1 of the Environmental Protection Act (MOE, 2011)

These standards present criteria 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 criteria are those for the Full Depth Background Conditions (Table 1 of MOE, 2011). For these conditions, the soil and sediment criteria 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.

A less conservative but still appropriate set of criteria are those for the Generic Site Condition Standards for Use within 30 m of a Water Body in a Potable Ground Water Condition (Table 8 of MOE, 2011). These standards are derived with the objective of protecting surface water bodies from movement of contaminants in soil into surface water and of protecting aquatic life from groundwater uptake (assuming no groundwater dilution for aquatic protection pathway).

The Full Depth Background Conditions (Table 1 of MOE, 2011) are cited as minimum criteria, while the Generic Site Condition Standards for Use within 30 m of a Water Body in a Potable Ground Water Condition (Table 8 of MOE, 2011) are cited as interim acceptance criteria because they are less conservative than the background conditions standard, but still adequately protective of ecosystems and human health.

MOE (2011) presents two different types of boron parameters in surface soils: one for total boron and one for a hot water soluble extract. The hot water soluble value is designed for the protection of plants and soil invertebrates and is more restrictive than the total boron value. However, a hot water soluble value is not provided for the Full Depth Background Conditions (Table 1 of MOE, 2011). Therefore, the value provided in the Generic Site Condition Standards for Use within 30 m of a Water Body in a Potable Ground Water Condition (Table 8 of MOE, 2011) is cited as the most conservative criterion for boron from MOE (2011).

C. Ontario’s Ambient Air Quality Criteria (MOE, 2012a)

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. The lowest available AAQC, which are also those with the longest averaging times (24 hours to 1 year), are cited for each element. AACQs are listed for both compounds and elements; only the elemental data was cited from this report.

D. Summary of Standards and Guidelines to Support Ontario Regulation 419/05: Air Pollution-Local Air Quality (MOE, 2012b)

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. The lowest available criteria, which are also those with the longest averaging times (½ hour to 1 year), are cited for each element.

E. Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario (MOEE, 1993)

These guidelines replace the ministry's sediment quality guidelines of 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. The only NEL values listed in the report are for chemical compounds, which do not serve to populate a list of criteria for chemical elements.

5.2 SECONDARY REFERENCES

The secondary references are used to supplement the primary 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.

A. Maximum Permissible Concentrations and Negligible Concentrations for Rare Earth Elements (Sneller et al. 2000)

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.

B. Guidance for Ecological Risk Assessments (ODEQ, 2001)

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 (2001) presents freshwater and marine (saltwater) values; but only the freshwater values are cited from this report since it is not anticipated that the repository will be sited near saltwater.

C. Toxicological Benchmarks for Screening Contaminants of Concern for Effects on Aquatic Biota (Suter and Tsoa, 1996)

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. Criteria cited from the report correspond to the minimum available values.

D. Protective Action Criteria for Chemicals (EMI SIG, 2012)

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. With the exception of the criterion for fluorine and iodine, all criteria quoted from this report correspond to the airborne concentration above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic, non-sensory effects when exposed for more than one hour (EMI SIG, 2012). The fluorine and iodine criteria are intended to limit the same effects, but for an exposure period of less than an hour. These are intended for acute not chronic exposure.

6. MINIMUM CRITERIA

The minimum criteria for each media are selected as the minimum values available over all the primary references, supplemented as required by the minimum values available over all the secondary references. Criteria from the secondary references are only shown for elements that have no criteria in any of the primary references. The lowest available criteria, considering plausible speciation of the element, are selected. When criteria are based on a particular species or a particular type of compound, these are specified. The minimum criteria for all elements from each of the primary and secondary references (as selected) are shown for all media in Table 6-1 to Table 6-5. The shaded cells in these tables indicate that criteria from the secondary references are not required. A summary of the selected minimum criteria is shown in Table 8-1.

Table 6-1: Minimum Criteria for Surface Water

Chemical Elements	Primary References (µg/L)				Secondary References (µg/L)			Selected Minimum Criteria (µg/L)
	MOEE (1994)	CCME (2014c)	CCME (2014d)	HC (2012)	OEDQ (2001)	Sneller et al. (2000)	Suter & Tsoa (1996)	
Ag	0.1		0.1					0.1
Al	15	5000	5	100				5
As	5	25	5	10				5
B	200	500	1500	5000				200
Ba				1000				1000
Be	11	100						11
Ca		1000 000						1000 000
Cd	0.1	5.1	0.09	5				0.09
Ce						22		22
Cl		100 000[a]	120 000[a]	250 000[a]				100 000[a]
Co	0.6	50						0.6
Cr	100	4.9[b]	1[c]	50[c]				1[c]
Cu	1	200	2	1000				1
Dy						9.3		9.3
F		1000[d]	120[d]	1500				120[d]
Fe	300	5000	300	300				300
Gd						7.1		7.1
Hg	0.2	3	0.004[e]	1				0.004[e]
I	100							100
K					53 000		53 000	53 000
La						10		10
Li		2500						2500
Mg					82 000		82 000	82 000
Mn		200		50				50
Mo	10	10	73					10
Na				200 000				200 000
Nb					600			600
Nd						1.8		1.8
Ni	25	200	25					25
P	10[g]		4					4
Pb	1	100	1	10				1
Pr						9.1		9.1
S	1.9[h]	330 000[f]		50[i]				1.9[h]
Sb	20			6				6
Se	100	20	1	10				1
Sm						8.2		8.2
Sn					73		73	73
Sr					1500 000		1500	1500
Tl	0.3		0.8					0.3
U	5	10	15	20				5
V	7	100						7
W	30							30
Y						6.4		6.4
Zn	20	1000	30	5000				20
Zr	4							4

a Value for chloride used.

b Value for chromium III used.

c Value for chromium VI used

d Value for inorganic fluorides (HF, CaF_2, NaF and SF_6) used. Value expressed in µgF/L.

e Value for methyl mercury used. Value expressed in µgHg/L.

f Value for sulphate used. Value expressed in µgS/L.

g Value is for total phosphorus.

h Value for hydrogen sulphide used. Value expressed in µgS/L.

i Value for sulphide used.

Table 6-2: Minimum Criteria for Groundwater

Chemical Element	Primary References (µg/L)			Selected Minimum Criteria
	MOE (2011)[a]	HC (2012)	CCME (2014c)	
Ag	0.3			0.3
Al		100	5000	100
As	13	10	25	10
B	1700[b]	5000	500	500
Ba	610	1000		610
Be	0.5		100	0.5
Ca			1000 000	1000 000
Cd	0.5	5	5.1	0.5
Cl	790 000[c]	250 000[c]	100 000[c]	100 000[c]
Co	3.8		50	3.8
Cr	11[d]	50[e]	4.9[f]	4.9[f]
Cu	5	1000	200	5
F		1500	1000[g]	1000[g]
Fe		300	5000	300
Hg	0.1	1	3	0.1
Li			2500	2500
Mn		50	200	50
Mo	23		10	10
Na	490 000	200 000		200 000
Ni	14		200	14
Pb	1.9	10	100	1.9
S		50[h]		50[h]
Sb	1.5	6		1.5
Se	5	10	20	5
Tl	0.5			0.5
U	8.9	20	10	8.9
V	3.9		100	3.9
Zn	160	5000	1000	160

a Values correspond to the Full Depth Background Site Condition Standard of MOE (2011).
b Value is for total boron.
c Value for chloride used.
d Value for total chromium used.
e Value is for chromium VI.
f Value for chromium III used.
g Value for inorganic fluorides (HF, CaF_2, NaF and SF_6) used. Value expressed in µgF/L.
h Value for sulphide used.

Table 6-3: Minimum Criteria for Soil

Chemical Element	Primary References (µg/g)		Secondary References (µg/g)		Selected Minimum Criteria (µg/g)
	MOE (2011)[a]	CCME (2014b)	OEDQ (2001)	Sneller et al. (2000)	
Ag	0.5	20			0.5
Al			50		50
As	11	12			11
B	1.5[b]	2			1.5[b]
Ba	210	500			210
Be	2.5	4			2.5
Bi			20		20
Br			10		10
Cd	1	1.4			1
Ce				53	53
Co	19	40			19
Cr	0.66[c]	0.4[c]			0.4[c]
Cu	62	63			62
F		200[d]			200[d]
Fe			200[f]		200[f]
Hg	0.16	6.6			0.16
I			4		4
La			50		50
Li			2		2
Mn			100[g]		100[g]
Mo	2	5			2
Nb			9		9
Ni	37	50			37
Pb	45	70			45
S		500			500
Sb	1	20			1
Se	1.2	1			1
Sn		5			5
Sr			33 000		33000
Tc			0.2		0.2
Te			250[e]		250[e]
Ti			1000		1000
Tl	1	1			1
U	1.9	23			1.9
V	86	130			86
W			400		400
Zn	290	200			200
Zr			97		97

[a] Correspond to the Full Depth Background Site Condition Standards (Table 1) in MOE (2011), except for value for B, which is corresponds the value from the Generic Site Condition Standards for Use within 30 m of a Water Body in a Potable Ground Water Condition (Table 8).

[b] Value for hot water soluble boron used.

[c] Value for chromium VI used.

[d] Value for total fluoride used.

[e] Value converted from a soil solution value to a soil concentration value using a soil Kd 0.125 m^3/kg for sandy soils and a water density of 1000 kg/m^3.

[f] Value for invertebrates is used, since it becomes the limiting value after the soil basis conversion on plant value.

[g] Value is also protective of simple chemical compounds of this element.

Table 6-4: Minimum Criteria for Sediment

Chemical Element	Primary References (µg/g)				Secondary References (µg/g)		Selected Minimum Criteria (µg/g)
	MOE (2011)[a]	CCME (2014a)	MOEE (1993)	Thompson et al. (2005)	OEDQ (2001)	Sneller et al. (2000)	
Ag	0.5						0.5
As	6	5.9	6	9.3			5.9
Cd	0.6	0.6	0.6				0.6
Ce						19 000	19 000
Co	50						50
Cr	26[b]	37[b]	26[b]	37			26[b]
Cu	16	36	16	12			12
Dy						2200	2200
Fe			21 000				21 000
Gd						1800	1800
Hg	0.2	0.17	0.2				0.17
La						4700	4700
Mn			460		1100[c]		460
Mo				8.3			8.3
Nd						7500	7500
Ni	16		16	21			16
Pb	31	35	31	28			28
Pr						5800	5800
Sb					3[c]		3
Se				0.9			0.9
Sm						2500	2500
U				32			32
V				27			27
Y						1400	1400
Zn	120	123	120				120

a Correspond to the Full Depth Background Site Condition Standards of MOE (2011).

b Value for total chromium used.

c Value is also protective of simple chemical compounds of this element.

Table 6-5: Minimum Criteria for Air

Chemical Element	Primary References (µg/m^3)		Secondary Reference (µg/m^3)	Selected Minimum Criteria (µg/m^3)
	MOE (2012a)	MOE (2012b)	EMI SIG (2012)[a]	
Ag	1	1	*100*	1
Al	63[c]	53[c]	*3000*	53[c]
As	0.3[b]	0.3[b]	*30*	0.3[b]
B	5.8[d]	5.8[d]	*7900*	5.8[d]
Ba	10	10	*1500*	10
Be	0.01[b]	0.01[b]	*2.3*	0.01[b]
Bi			15 000	100[a]
Br	20	20	*220*	20
Ca			30 000	200[a]
Cd	0.005[b]	0.025[b]	*100*	0.005
Ce			30 000	200[a]
Cl	10	10	*1400*	10
Co	0.1	0.1	*180*	0.1
Cr			1500	10[a]
Cu	50	50	*1000*	50
Dy			30 000	200[a]
Eu			30 000	200[a]
F			2600	17[a]
Fe	4	4	*1000*	4
Gd			51 000	340[a]
Hf			1500	10[a]
Hg	0.5[e]	0.5[e]	*150*	0.5[e]
Ho			6000	40[a]
I			100	0.67[a]
K			2300	15[a]
La			30 000	200[a]
Li	20	20	*560*	20
Lu			1200	8[a]
Mg			16	0.11[a]
Mn	0.1[b]	0.4[b]	*3000*	0.1[b]
Mo	120	100	*10 000*	100
Na			13 000	87[a]
Nb			30 000	200[a]
Nd			30 000	200[a]
Ni	0.02[b]	0.04[b]	*4500*	0.02[b]
Pb	0.2[b]	0.2[b]	*150*	0.2[b]
Pr			1200	8[a]
Pt	0.2[b]	0.2[b]	*3000*	0.2[b]
S	7[g]	7[g]	*2800*	7[g]
Sb	25[b]	25	*500*	25[b]
Sc			30 000	200[a]
Se	10	10	*200*	10
Sm			30 000	200[a]
Sn	10	10	*6000*	10
Sr	120	100	*7100*	100
Ta			10 000	67[a]
Tb			1200	8[a]
Te	10	10	*1800*	10
Ti	20[f]	20[f]	*120*	20[f]
Tl			60	0.4[a]
Tm			30 000	200[a]
U	0.03[b]	0.03[b]	*600*	0.03[b]

Chemical Element	Primary References ($\mu g/m^3$)		Secondary Reference ($\mu g/m^3$)	Selected Minimum Criteria ($\mu g/m^3$)
	MOE (2012a)	MOE (2012b)	EMI SIG (2012)[a]	
V	2	2	*110*	2
W			10 000	67[a]
Y			3000	20[a]
Zn	120	100	*1900*	100
Zr			*10 000*	67

[a] The EMI SIG (2012) criteria are significantly higher than the MOE (2012a and 2012b) criteria because they are intended as acute criteria for emergency situations, whereas the MOE (2012a and 2012b) are intended to protect from chronic releases. Therefore, the EMIG SIG (2012) values selected here are reduced by a factor of 150 if adopted as chronic criteria. This factor is the median ratio between EMI SIG (2012) values and known criteria from the primary references.

[b] Value is also protective of simple chemical compounds of this element.

[c] Value for aluminum oxide used. Value expressed in $\mu gAl/m^3$.

[d] Value for boric acid used. Value expressed in $\mu gB/m^3$.

[e] Value for mercury alkyl compounds used. Value expressed in $\mu gHg/m^3$.

[f] Value for titanium dioxide used. Value expressed in $\mu gTi/m^3$.

[g] Value for hydrogen sulphide used. Value expressed in $\mu gS/m^3$.

7. INTERIM ACCEPTANCE CRITERIA

As mentioned in Section 3, the interim acceptance criteria are developed using the minimum criteria as a basis. For instances where the criteria in the primary references are specified by a range, dependent on specific conditions, or exceedingly conservative, alternative interim acceptance criteria may be justifiable. The following sections identify the contaminants for which the interim acceptance criteria are justifiably different from the minimum criteria.

7.1 SURFACE WATER

The surface water criteria are generally based on either MOEE (1994) or CCME (2014d), which are intended for protection of human health and/or aquatic life. These are current standards and would need to be met. However for some elements, the criterion may depend on the pH or the calcium carbonate concentration in the water. Table 7-1 identifies the elements for which a range is specified by the primary references. While the minimum criteria in Table 6-1 are the lowest range values, the recommended interim acceptance criteria include the ranges.

Table 7-1: Interim Acceptance Criteria for Surface Water

Chemical Element	MOEE (1994)	CCME (2014c)	CCME (2014d)	Selected Interim Acceptance Criteria
Al	15 to 75, depending on pH	No range	5 or 100, depending on pH	= 5 µg/L if pH < 6.5 = 100 µg/L if pH ≥ 6.5
Be	11 to 1100, depending on hardness as $CaCO_3$	No range	No value	=11 µg/L if $CaCO_3$ ≤75 mg/L =1100 µg/L if $CaCO_3$ > 75 mg/L
Cu	1 or 5, depending on hardness as $CaCO_3$	200 to 1000 depending on the agricultural product being protected.	2 to 4, depending on hardness as $CaCO_3$	=1 µg/L $CaCO_3$≤20 mg/L =5 µg/L $CaCO_3$>20 mg/L
Ni	No range	No range	25 to 150, depending on hardness as $CaCO_3$	= 25 µg/L if $CaCO_3$≤ 60 mg/L = $e^{\{0.76[\ln(\underline{hardness})]+1.06\}}$ µg/L if $CaCO_3$> 60 and ≤ 180 mg/L =150 µg/L if $CaCO_3$>180 mg/L
Pb	1 to 5 depending on hardness as $CaCO_3$	No range	1 to 7, depending on hardness as $CaCO_3$	=1 µg/L if $CaCO_3$ <30 mg/L =3 µg/L if $CaCO_3$ is ≥30 but ≤80 mg/L =5 µg/L if $CaCO_3$ >80 mg/L
Zn	No range	1000 or 5000 depending on pH	No range	= 1000 µg/L when soil pH ≤ 6.5* = 5000 µg/L when soil pH > 6.5*

* The soil pH is specified because it is an irrigation water criterion.

The minimum criterion for sulphur in surface water corresponds to the criterion for hydrogen sulphide from MOEE (1994), since it is the lowest sulphur based criterion in the primary references. However, given that sulphur may, under a range of natural conditions, exist as sulphate, which is much less toxic that hydrogen sulphide, the criterion for sulphate in surface water is added as an option in the interim acceptance criteria. Therefore, if the sulphur is known to exist as sulphate, the interim acceptance criterion is 170 000µg/L (HC, 2012), which is the lowest of the sulphate criteria in the primary references. Otherwise, the interim acceptance criterion is the same as the minimum criterion.

7.2 GROUNDWATER

MOE (2011) presents groundwater standards for different conditions. The Full Depth Background Condition standards (Table 1 of MOE (2011)), which are used to help define the minimum criteria for groundwater in this report (Table 6-2), are not based on potential effect concentrations but rather represent the upper normal range (greater than 97.5 percentile) of background concentrations across Ontario. As they are not based on potential effects concentrations, they may be prohibitively conservative in some cases.

The most conservative set of standards in MOE (2011) that are based on potential effects concentrations are those for the Generic Site Condition Standards for Use within 30 m of a Water Body in a Potable Groundwater Condition (Table 8, MOE (2011)). These are selected as acceptance criteria when the HC (2012) and CCME (2014c) criteria are not more conservative. They are shown below in Table 7-2.

The minimum criterion for sulphur in groundwater corresponds to the criterion for sulphide from HC (2012), since it is the lowest sulphur based criterion in the primary references. However, given that sulphur may, under a range of natural conditions, exist as sulphate, which is much less toxic that sulphide, the criterion for sulphate in surface water is added as an option in the interim acceptance criteria. Therefore, if the sulphur is known to exist as sulphate, the interim acceptance criterion is 170 000µg/L (HC, 2012), which is the lowest of the sulphate criteria in the primary references. Otherwise, the interim acceptance criterion is the same as the minimum criterion.

Except for the sulphur criterion, the interim acceptance criteria for elements not shown in Table 7-2 are unchanged from the minimum criteria in Table 6-2.

Table 7-2: Interim Acceptance Criteria for Groundwater

Chemical Element	Criteria (µg/L)
Ag	1.2
Ba	1000
Be	4
Cd	2.1
Cu	69
Hg	0.12[a]
Ni	100
Pb	10
Sb	6
Se	10
Tl	2
U	20
V	6.2
Zn	890
All others[b]	See Table 6-2

a Hg value is represented by methyl mercury.

b Except for S. See text above.

7.3 SOIL

MOE (2011) presents soil standards for different conditions. The Full Depth Background Condition standards (Table 1 of MOE (2011)), which are used to help define the minimum criteria for soil in this report (Table 6-3), are not based on potential effect concentrations but rather represents the upper normal range (greater than 97.5 percentile) of background concentrations across Ontario. As they are not based on potential effects concentrations, they may be prohibitively conservative in some cases.

The most conservative set of standards in MOE (2011) that are based on potential effect concentrations are those for the Generic Site Condition Standards for Use within 30 m of a Water Body in a Potable Groundwater Condition (Table 8, MOE (2011)). These are selected as acceptance criteria when available, instead of the Full Depth Background Condition standards and the criteria from CCME (2014b). The interim acceptance criteria for all other contaminants are the same as the minimum criteria.

Table 7-3: Interim Acceptance Criteria for Soil

Element	Criteria (µg/g)
Co	22
Cr	0.66
Hg	0.2
Se	1.2
Zn	290
All Others	See Table 6-3

7.4 SEDIMENT

No alternative basis for criteria for sediment is presented in any of the primary references, and the recommended criteria values are similar. Therefore the interim acceptance criteria are the same as the minimum criteria, for all elements.

7.5 AIR

No alternative basis for criteria for air is presented in any of the primary references, and the recommended criteria values are similar. Therefore the interim acceptance criteria are the same as the minimum criteria, for all elements.

8. SUMMARY

Interim acceptance criteria for the protection of persons and the environment from non-radiological release of hazardous chemical elements associated with a deep geological repository for used nuclear fuel have been identified. Criteria are presented for five environmental media (surface water, groundwater, soil, sediment and air) and are based on Canadian Federal and Provincial Guidelines and publications, supplemented as needed by international references. As discussed in Section 4, there are some elements for which criteria do not exist; further work is required to identify if any of these may be of potential concern to the safety of a repository. Minimum criteria were established representing the lowest possible criteria for all conditions, and interim acceptance criteria were determined by taking into consideration the conditions under which the criteria are meant to be applied. The minimum criteria are summarized in Table 8-1 and the interim acceptance criteria are summarized in Table 8-2.

Table 8-1: Summary of Minimum Criteria

Chemical Element	Surface Water (µg/L)		Groundwater (µg/L)		Soil (µg/g)		Sediment (µg/g)		Air (µg/m^3)	
Ag	0.1	d, h	0.3	a	0.5	a	0.5	a	1	b, c
Al	5	h	100	j	50	l	-	-	53	c, aa
As	5	d, h	10	j	11	a	5.9	i	0.3	b, c, w
B	200	d	500	g	1.5	a,gg	-	-	5.8	b, c, bb
Ba	1000	j	610	a	210	a	-	-	10	b, c
Be	11	d	0.5	a	2.5	a	-	-	0.01	b, c, w
Bi	-	-	-	-	20	l	-	-	100	o
Br	-	-	-	-	10	l	-	-	20	b, c
Ca	1000 000	g	1000 000	g	-	-	-	-	200	o
Cd	0.09	h	0.5	a	1	a	0.6	a, e, i	0.005	b, c, w
Ce	22	m	-	-	53	m	19 000	m	200	o
Cl	100 000	g, u	100 000	g, u	-	-	-	-	10	b, c
Co	0.6	d	3.8	a	19	a	50	a	0.1	b, c
Cr	1	h, q	4.9	g, r	0.4	f, q	26	a, e, p	10	o
Cu	1	d	5	a	62	a	12	k	50	b, c
Dy	9.3	m	-	-	-	-	2200	m	200	o
Eu	-	-	-	-	-	-	-	-	200	o
F	120	h, s	1000	g, s	200	f, t	-	-	17	o
Fe	300	d, h	300	j	200	l	21 000	e	4	b, c
Gd	7.1	m	-	-	-	-	1800	m	340	o
Hf	-	-	-	-	-	-	-	-	10	o
Hg	0.004	h, x	0.1	a	0.16	a	0.17	i	0.5	b, c, z
Ho	-	-	-	-	-	-	-	-	40	o
I	100	d	-	-	4	l	-	-	0.67	o
K	53 000	l, n	-	-	-	-	-	-	15	o
La	10	m	-	-	50	l	4700	m	200	o
Li	2500	g	2500	g	2	l	-	-	20	b, c
Lu	-	-	-	-	-	-	-	-	8	o
Mg	82 000	l, n	-	-	-	-	-	-	0.11	o
Mn	50	j	50	j	100	l, w	460	e	0.1	b, w
Mo	10	d,g	10	g	2	a	8.3	k	100	c
Na	200 000	j	200 000	j	-	-	-	-	87	o
Nb	600	l	-	-	9	l	-	-	200	o
Nd	1.8	m	-	-	-	-	7500	m	200	o
Ni	25	d, h	14	a	37	a	16	a, e	0.02	b, w
P	4	h	-	-	-	-	-	-	-	-
Pb	1	d, h	1.9	a	45	a	28	k	0.2	b, c, w
Pr	9.1	m	-	-	-	-	5800	m	8	o
Pt	-	-	-	-	-	-	-	-	0.2	b, c, w
S	1.9	d, ff	50	j, y	500	f	-	-	7	b, c, ff
Sb	6	j	1.5	a	1	a	3	l	25	b, c, w
Sc	-	-	-	-	-	-	-	-	200	o
Se	1	h	5	a	1	f	0.9	k	10	b, c
Sm	8.2	m	-	-	-	-	2500	m	200	o
Sn	73	l, n	-	-	5	f	-	-	10	b, c
Sr	1500	l	-	-	33 000	l	-	-	100	c
Ta	-	-	-	-	-	-	-	-	67	o
Tb	-	-	-	-	-	-	-	-	8	o
Tc	-	-	-	-	0.2	l	-	-	-	-
Te	-	-	-	-	250	l, v	-	-	10	b, c
Ti	-	-	-	-	1000	l	-	-	20	b, c, cc
Tl	0.3	d	0.5	a	1	a, f	-	-	0.4	o
Tm	-	-	-	-	-	-	-	-	200	o
U	5	d	8.9	a	1.9	a	32	k	0.03	b, c, w
V	7	d	3.9	a	86	a	27	k	2	b, c

Chemical Element	Surface Water (µg/L)		Groundwater (µg/L)		Soil (µg/g)		Sediment (µg/g)		Air (µg/m^3)	
W	30	d	-	-	400	l	-	-	67	o
Y	6.4	m	-	-	-	-	1400	m	20	o
Zn	20	d	160	a	200	f	120	a, e	100	c
Zr	4	d	-	-	97	l	-	-	67	o

a MOE (2011). Table 1. Used ‘Agricultural or Other Property Use’ values for soil. Value for B is from Table 8.
b MOE (2012a). Used lowest available criteria.
c MOE (2012b). Used lowest available criteria.
d MOEE (1994). Used lowest available criteria.
e MOEE (1993). Used lowest available criteria.
f CCME (2014b). Used lowest available criteria.
g CCME (2014c). Used lowest available criteria.
h CCME (2014d). Used freshwater values.
i CCME (2014a). Used freshwater values.
j HC (2012). Used lowest available criteria.
k Thompson et al. (2005). Used Lowest Effect Level value.
l ODEQ (2001). Used lowest available for each media.
m Sneller et al. (2000). Used MPCs for freshwater.
n Suter and Tsoa (1996). Used Tier II secondary chronic value.
o EMI SIG (2012). Reduced PAC1 values by a factor of 150. See Section 6.
p Values for total Cr used.
q Values for Cr VI used.
r Value for Cr III used.
s Value for inorganic fluorides (HF, CaF_2, NaF and SF_6) used. Value expressed in µgF/L.
t Value for total fluorides used.
u Value for chloride used.
v Converted from soil solution with soil distribution coefficient of 0.125 m^3/kg for sandy soil (CSA, 2008).
w Value is also protective of simple chemical compounds of this element.
x Value for methyl mercury used. Value expressed in µgHg/L.
y Value for sulphide used.
z Value for mercury alkyl compounds used. Value expressed in µgHg/m^3.
aa Value for aluminum oxide used. Value expressed in µgAl/m^3.
bb Value for boric acid used. Value expressed in µgB/m^3.
cc Value for titanium dioxide used. Value expressed in µgTi/m^3.
ff Value for hydrogen sulphide used. Value expressed in µgS/L or µgS/ m^3.
gg Value for hot water soluble boron used.
\- Not available.

Table 8-2: Summary of Interim Acceptance Criteria

Element	Surface Water (µg/L)		Groundwater (µg/L)		Soil (µg/g)		Sediment (µg/g)		Air ($\mu g/m^3$)	
Ag	0.1	d, h	1.2	a	0.5	a	0.5	a	1	b, c
Al	=5 if pH<6.5 =100 if pH is ≥6.5	h	100	j	50	l	-	-	53	c, aa
As	5	d, h	10	j	11	a	5.9	i	0.3	b, c, w
B	200	d	500	g	1.5	a, hh	-	-	5.8	b, c, bb
Ba	1000	j	1000	a	210	a	-	-	10	b, c
Be	=11 if $CaCO_3$ < 75 mg/L =1100 if $CaCO_3$ > 75 mg/L	d	4	a	2.5	a	-	-	0.01	b, c, w
Bi		-	-	-	20	l	-	-	100	o
Br	-	-	-	-	10	l	-	-	20	b, c
Ca	1000 000	g	1000 000	g	-	-	-	-	200	o
Cd	0.09	h	2.1	a	1	a	0.6	a, e, i	0.005	b, c, w
Ce	22	m	-	-	53	m	19 000	m	200	o
Cl	100 000	g, u	100 000	g, u	-	-	-	-	10	b, c
Co	0.6	d	3.8	a	22	a	50	a	0.1	b, c
Cr	1	h, q	4.9	g, r	0.66	a, q	26	a, e ,p	10	o
Cu	=1 $CaCO_3$ ≤ 20 mg/L =5 $CaCO_3$ > 20 mg/L	d	69	a	62	a	12	k	50	b, c
Dy	9.3	m	-	-	-	-	2200	m	200	o
Eu	-	-	-	-	-	-	-	-	200	o
F	120	h, s	1000	g, s	200	f, t	-	-	17	o
Fe	300	d, h	300	j	200	l	21 000	e	4	b, c
Gd	7.1	m	-	-	-	-	1800	m	340	o
Hf	-	-	-	-	-	-	-	-	10	o
Hg	0.004	h, x	0.12	a	0.2	a	0.17	i	0.5	b, c, z
Ho	-	-	-	-	-	-	-	-	40	o
I	100	d	-	-	4	l	-	-	0.67	o
K	53 000	l, n	-	-	-	-	-	-	15	o
La	10	m	-	-	50	l	4700	m	200	o
Li	2500	g	2500	g	2	l	-	-	20	b, c
Lu	-	-	-	-	-	-	-	-	8	o
Mg	82 000	l, n	-	-	-	-	-	-	0.11	o
Mn	50	j	50	j	100	l, w	460	e	0.1	b, w
Mo	10	d, g	10	g	2	a	8.3	k	100	c
Na	200 000	j	200 000	j	-	-	-	-	87	o
Nb	600	l	-	-	9	l	-	-	200	o
Nd	1.8	m	-	-	-	-	7500	m	200	o
Ni	= 25 if $CaCO_3$≤ 60 mg/L =$e^{\{0.76[\ln(\underline{hardness})]+1.06\}}$ if $CaCO_3$> 60 and ≤ 180 mg/L =150 if $CaCO_3$ >180 mg/L	h	100	a	37	a	16	a, e	0.02	b, w
P	4	h	-	-	-	-	-	-	-	-
Pb	=1 if $CaCO_3$ <30 mg/L =3 if $CaCO_3$ is ≥ 30 but ≤80 mg/L =5 if $CaCO_3$ > 80 mg/L	d	10	a	45	a	28	k	0.2	b, c, w
Pr	9.1	m	-	-	-	-	5800	m	8	o

Element	Surface Water (µg/L)		Groundwater (µg/L)		Soil (µg/g)		Sediment (µg/g)		Air (µg/m^3)	
Pt	-	-	-	-	-	-	-	-	0.2	b, c, w
S	= 170 000 if S exists as sulphate =1.9 if S exists in any other form	j, y d, ff	=170 000 if S exists as sulphate =50 if S exists in any other form	j, y j, gg	500	f	-	-	7	b, c ,ff
Sb	6	j	6	a	1	a	3	l	25	b, c, w
Sc	-	-	-	-	-	-	-	-	200	o
Se	1	h	10	a	1.2	a	0.9	k	10	b, c
Sm	8.2	m	-	-	-	-	2500	m	200	o
Sn	73	l,n	-	-	5	f	-	-	10	b, c
Sr	1500	l	-	-	33 000	l	-	-	100	c
Ta	-	-	-	-	-	-	-	-	67	o
Tb	-	-	-	-	-	-	-	-	8	o
Tc	-	-	-	-	0.2	l	-	-	-	-
Te	-	-	-	-	250	l, v	-	-	10	b, c
Ti	-	-	-	-	1 000	l	-	-	20	b, c, cc
Tl	0.3	d	2	a	1	a, f	-	-	0.4	o
Tm	-	-	-	-	-	-	-	-	200	o
U	5	d	20	a	1.9	a	32	k	0.03	b, c, w
V	7	d	6.2	a	86	a	27	k	2	b, c
W	30	d	-	-	400	l	-	-	67	o
Y	6.4	m	-	-	-	-	1400	m	20	o
Zn	=1000 if soil pH ≤6.5 =5000 if soil pH > 6.5	g, dd	890	a	290	a	120	a, e	100	c
Zr	4	d	-	-	97	l	-	-	67	o

a MOE (2011). Table 8. Used ‘Agricultural or Other Property Use’ values for soil.
b MOE (2012a). Used lowest available criteria.
c MOE (2012b). Used lowest available criteria.
d MOEE (1994). Used lowest available criteria.
e MOEE (1993). Used lowest available criteria.
f CCME (2014b). Used lowest available criteria.
g CCME (2014c). Used lowest available criteria.
h CCME (2014d). Used freshwater values.
i CCME (2014a). Used freshwater values.
j HC (2012). Used lowest available criteria.
k Thompson et al. (2005). Used Lowest Effect Level value.
l ODEQ (2001). Used lowest available for each media.
m Sneller et al. (2000). Used MPCs for freshwater.
n Suter and Tsoa (1996). Used Tier II secondary chronic value.
o EMI SIG (2012). Reduced PAC1 values by a factor of 150. See Section 6.
p Values for total Cr used.
q Values for Cr VI used.
r Value for Cr III used.
s Value for inorganic fluorides (HF, CaF$_2$, NaF and SF$_6$) used. Value expressed in µgS/L.
t Value for total fluorides used.
u Value for chloride used.
v Converted from soil solution with soil distribution coefficient of 0.125 m3/kg for sandy soil (CSA, 2008).
w Value is also protective of simple chemical compounds of this element.
x Value for methyl mercury used. Value expressed in µgS/L.
y Value for sulphate used. Value expressed in µgS/L.
z Value for mercury alkyl compounds used. Value expressed in µgHg/m^3.
aa Value for aluminum oxide used. Value expressed in µgAl/m^3.
bb Value for boric acid used. Value expressed in µgB/m^3.
cc Value for titanium dioxide used. Value expressed in µgTi/m^3.
dd Soil pH is specified because it is an irrigation water criterion.
ff Value for hydrogen sulphide used. Value expressed in µgS/m^3.
gg Value for sulphide used.
hh Value for hot water soluble boron used.
\- Not available.

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APPENDIX A: COMPOUNDS TO CONSIDER

Some of the primary references provide criteria based on specific chemical compounds. In the present report, chemical compounds are explicitly considered where such criteria are available; however, this information is then considered implicitly within the criteria of their most dominant element. That is, the element criterion is based on the lowest of the elemental or relevant compound criteria.

Not all chemical compounds that are listed in the primary references are likely to form or to be of concern in the postclosure phase of the repository. Tables A-1 and A-2 provides justification for inclusion or exclusion of these compounds for consideration of criteria.

Note also that the following assessment applies only to elements identified as of interest, and in particular does not include compounds of C, N, H and O. If specific chemical compounds are considered likely to form and be relevant to releases, they may need to be explicitly considered in a safety assessment.

Table A-1: Justification for Inclusion of Chemical Compounds cited in Primary References for Surface Water, Groundwater, Soil and Sediment

Compounds	References	Inclusion	Justification
Bromate (BrO_3^-)	HC (2012)	No	Bromine is likely released from the repository as the bromide anion. Formation of bromate from bromide in natural systems is unlikely given that bromate is a powerful oxidizing agent that readily reacts with organics to produce bromide.
Bromoform ($CHBr_3$)	MOEE (1994)	No	Bromine is likely released from the repository as the bromide anion. Bromide is not likely to be converted to bromoform in natural systems. Bromoform is broken down slowly under aerobic conditions and more rapidly under anaerobic conditions.
Hydrogen Sulphide **Sulphide**	MOEE(1994) HC (2012)	Yes	Sulphur is likely released from the repository as the sulphate cation. Sulphides, including hydrogen sulphide, could in theory be formed from sulphate by sulphate reducing bacteria. Note that sulphides do not persist in the biosphere – they slowly react with oxygen to produce sulphur and/or sulphur oxides, and with some metal ions (e.g., iron) to form insoluble sulphides (thereby decreasing dissolved sulphide concentrations).
Sulphate	HC (2012)	Yes	Sulphur is likely released from the repository as the sulphate cation. Sulphate is likely the major sulphur compound in the biosphere.
Mercury Alkyl Compounds	CCME (2014d) MOE (2011)	Yes	Mercury can be transformed through abiotic and biotic processes to form alkyl mercury compounds. Thus, mercury alkyl compounds, e.g., methyl mercury, could form from mercury released from the repository.
Reactive chlorine Species	CCME (2014d) HC (2012)	No	Chlorine is likely released from the repository as the chloride anion. Formation of reactive chlorine species such as chlorate and chlorite (powerful oxidizing agents) from chloride is unlikely since chloride is not easily oxidized in natural systems.

Table A-2: Justification for Inclusion of Chemical Compounds cited in Primary References for Air

Compounds	References	Inclusion	Justification
Aluminum Oxide	MOE (2012a) MOE (2012b)	Yes	Aluminum released from the repository could, in theory, reach the biosphere, where it would likely precipitate as aluminum oxide. Aluminum oxide is non-volatile; however, if formed in soils, it could become airborne due to wind erosion of soil.
Boric Acid	MOE (2012a) MOE (2012b)	Yes	Boron released from the repository could, in theory, reach the biosphere where it could form boric acid. Boric is a weak acid that exists in neutral aqueous solutions as undissociated boric acid. While boric acid is non-volatile, it could become airborne (likely as borate salt) due to wind erosion of the soil.
Calcium Hydroxide	MOE (2012a)	No	Calcium would likely be released from the repository as the calcium cation. Undissociated calcium hydroxide cannot form under natural conditions (e.g., neutral pH values).
Calcium Oxide	MOE (2012a) MOE (2012b)	No	Calcium would likely be released from the repository as the calcium cation. Calcium oxide cannot form in the presence of water since it reacts with water to form a calcium hydroxide. See justification for calcium hydroxide.
Chlorine Dioxide	MOE (2012b)	No	Chlorine is likely released from the repository as the chloride anion. Formation of reactive chlorine species such as chlorine dioxide from chloride is unlikely since chloride is not easily oxidized in natural systems.
Ferric Oxide	MOE (2012a) MOE (2012b)	Yes	Iron released from the repository could, in theory, reach the biosphere, where it would likely precipitated as an iron oxide. Ferric oxide is non-volatile; however, if formed in soils it could become airborne due to wind erosion of soil.
Fluorides	MOE (2012b)	Yes	Fluorine is likely released from the repository as the fluoride anion. Although fluorides are generally non-volatile, fluorides reaching the top soil layers in the biosphere could become airborne due to wind erosion of soil.
Hydrogen Bromide	MOE (2012b)	No	Bromine is likely released from the repository as the bromide anion. Formation of (undissociated) hydrogen bromide, a strong acid that dissociates on contact with water, is not likely under natural conditions.
Hydrogen Chloride	MOE (2012a) MOE (2012b)	No	Chlorine is likely released from the repository as the chloride anion. Formation of (undissociated) hydrogen chloride, a strong acid that dissociates on contact with water, is not likely under natural conditions.
Hydrogen Sulphide	MOE (2012a) MOE (2012b)	Yes	Sulphur is likely released from the repository as the sulphate cation. Hydrogen sulphide could in theory be formed from sulphate by sulphate reducing bacteria. Note that hydrogen sulphide does not persist in the biosphere – it slowly reacts with oxygen to produce sulphur and/or sulphur oxides, and with metal ions to form insoluble sulphides.
Sulfamic Acid	MOE (2012b)	No	Sulphur would likely be released from the repository as the sulphate cation. Formation of sulfamic acid, a strong unstable acid, from dissolved sulphate is not likely in natural systems.

Compounds	References	Inclusion	Justification
Sulphur Dioxide	MOE (2012a) MOE (2012b)	No	Sulphur would likely be released from the repository as the sulphate cation. Sulphate could be reduced to sulphite and sulfide by sulphate reducing bacteria. Any sulphite formed would likely not generate sulphur dioxide gas under natural (non-acidic) conditions. The criterion for sulphur dioxide is less restrictive than other sulphur compounds.
Sulphuric Acid	MOE (2012a) MOE (2012b)	No	Sulphur would likely be released from the repository as the sulphate cation. Formation of (undissociated) sulphuric acid, a strong acid that dissociates on contact with water, is not likely under natural conditions.
Lithium Hydrides	MOE (2012a) MOE (2012b)	No	Lithium is likely released from the repository as the lithium cation. Formation of lithium hydrides is not likely in the presence of water because lithium hydrides react rapidly with water and water vapour to form lithium hydroxide and hydrogen.
Magnesium Oxide	MOE (2012a) MOE (2012b)	No	Magnesium is likely released from the repository as the magnesium cation. Magnesium oxide cannot form in the presence of water since it reacts with water to form a magnesium hydroxide.
Mercury Alkyl Compounds	MOE (2012a) MOE (2012b)	Yes	Mercury released from the repository can be transformed through abiotic and biotic processes to form alkyl mercury compounds.
Phosphoric Acid	MOE (2012a)	No	Phosphorus is likely released from the repository as the phosphate anion. Formation of (undissocated) phosphoric acid, a strong acid that dissociates on contact with water, is not likely under natural conditions.
Potassium Hydroxides	MOE (2012a)	No	Potassium is likely released from the repository as the potassium cation. Potassium hydroxide, a strong base that dissociates in water, cannot form under natural conditions.
Sodium Hydroxide	MOE (2012a)	No	Sodium is likely released from the repository as the sodium cation. Sodium hydroxide, a strong base that dissociates in water, cannot form under natural conditions.
Strontium Hydroxide	MOE (2012a) MOE (2012b)	No	Strontium is likely released from the repository as the strontium cation. Strontium hydroxide, a strong base that dissociates in water, cannot form under natural conditions.
Strontium Oxide	MOE (2012a) MOE (2012b)	No	Strontium is likely released from the repository as the strontium cation. Strontium oxide cannot form in the presence of water since it reacts with water to form strontium hydroxide. See also justification for strontium hydroxide.
Titanium Dioxide	MOE (2012a) MOE (2012b)	Yes	Titanium released from the repository could, in theory, reach the biosphere, where it would likely precipitate as titanium dioxide. Titanium dioxide is non-volatile; however, if formed in soils, it could become airborne due to wind erosion of soil.