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Proposed Soil Quality Guidelines
Beryllium
Environmental Health Effects

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Table of Contents

Page

List of Figures

1.0 INTRODUCTION

Soil quality guidelines are numerical soil concentrations intended to be protective of human and environmental health for current and potential future uses of land. They are frequently used for the assessment and remediation of contaminated sites.

The Canadian Council of Ministers of the Environment (CCME) published "A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines" (CCME, 2006) to provide a framework and methodology for developing risk-based soil quality guidelines protective of human health and the environment; the guidelines developed using this protocol have been published in the Canadian Soil Quality Guidelines (CCME, 1999). The guidelines developed using this protocol have formed the basis for some provincial guidelines, including the Alberta Tier 1 Soil and Groundwater Remediation Guidelines (ESRD, 2014).

Using the 2006 protocol, the CCME Soil Quality Guidelines Task Group prepared a scientific criteria document (CCME, 2015) providing the background information and rationale for updated human health soil quality guidelines for beryllium (Be) based on four types of land use: agricultural, residential/parkland, commercial, and industrial. The guideline document did not include soil quality guidelines intended to be protective of environmental health, however. As a result, the earlier Interim Canadian Environmental Quality Criteria for Contaminated Sites (CCME, 1991), which did not use modern risk-based approaches, are still applied as the overall guideline.

The report herein provides proposed soil quality guidelines for beryllium intended to be protective of environmental health based on the CCME (2006) protocol. Guidelines are derived for the agricultural, residential/parkland, commercial and industrial land uses as defined by CCME (2006).

A detailed review of review of the chemical and physical properties of beryllium, the sources and emissions in Canada, the distribution and behaviour of beryllium in the environment and the toxicological effects of beryllium in humans can be found in the CCME (2015) criteria document. The document herein focuses on the toxicological effects on plants, invertebrates and livestock and wildlife species. The environmental health guidelines for beryllium in soil derived in this document are intended to be used in conjunction with the human health guidelines derived in the Health Canada (2013) document and published under CCME (2015).

2.0 BEHAVIOUR AND EFFECTS IN TERRESTRIAL BIOTA

The available information on the toxicological effects of beryllium on terrestrial plants, invertebrates, as well as livestock and wildlife species have been reviewed and summarized below.

Plants and animals may accumulate contaminants over time if the amount to which they are directly exposed is greater than the amount they can eliminate through excretion and metabolic processes.

Bioconcentration is the transfer of contaminants directly from a medium to an organism and the transfer of contaminants to an organism through the consumption of contaminated food is referred to as bioaccumulation (CCME, 2006).

2.1 Terrestrial Plants

2.1.1 Uptake, Metabolism and Elimination

Beryllium enters the environment principally from coal and fuel oil combustion. Since the major source of atmospheric beryllium is fossil fuel combustion, the most prevalent chemical form is likely beryllium oxide, mainly bound to particles smaller than 1 μm. (US EPA, 2005; CCME, 2015). Beryllium returns to earth through both wet and dry deposition in a similar manner to other metals and on particles of comparable size distribution (Kwapulinski & Pastuszka, 1983). Reactions of beryllium in solution and soil depend on the pH of the medium. At near neutral environmental pH ranges of 4 to 8, beryllium oxide is highly insoluble, thus preventing mobilization in soil. Beryllium is strongly adsorbed by finely dispersed sedimentary materials including clays, iron hydroxides, and organic substances (Izmerov, 1985). If beryllium oxide is converted to the ionized salts (chloride, fluoride, phosphate sulfate, nitrate) during atmospheric transport, solubility upon deposition and, hence, mobility in soils would be greatly enhanced, but this has not been reported in the literature (Bruce and Odin, 2001; US EPA, 2005).

If beryllium is bioavailable in the soil matrices, it can be assimilated by plants (ATSDR, 2002). The plant/soil transfer coefficient for beryllium has been estimated as 0.01–0.1, depending on plant species and soil properties (Kloke et al., 1984). In plants, uptake of beryllium appears to be restricted to the root system; no significant translocation of beryllium to the above ground parts of the plant has been observed. Romney and Childress (1965) examined uptake of ^{7}Be in beans, barley, sunflowers, and tomato plants. Over 95% of ^{7}Be was found in the roots; very little was translocated to the foliage and fruits. The Enrichment Ratio (ER) of beryllium in oat grain and in alfalfa grown in both microcosms and field plots amended with beryllium containing fly ash was 1 (Tolle et al. 1983 as cited by ATSDR, 2002). For collard seedlings, beryllium remains in the roots, and only small portions were translocated to above ground portions (Kaplan et al. 1990). Above-ground plant parts can also be contaminated via atmospheric deposition (Bruce and Odin, 2001).

2.1.2 Bioconcentration

Bioconcentration of beryllium in plants and animals is generally low (CCME, 2015).

Most plants take up beryllium from soil in small amounts, although a few species (e.g., hickory, birch, larch) act as beryllium accumulators (Nikonova, 1967; Griffitts et al., 1977; Newland, 1982). Some plant species from the *Leguminosae* and *Cruciferae* families can accumulate large amounts of beryllium

(Kabata-Pendias and Pendias 1992). Beryllium is generally found in plant samples at concentrations below 1 mg/kg dry weight (IPCS, 1990), although certain species that concentrate beryllium from soils may have concentrations up to 10 mg/kg dry weight (Nikonova, 1967; Griffitts et al., 1977). A plant/soil transfer coefficient range of 0.01 to 0.1 (varies according to plant species and soil properties) has been estimated for beryllium (Kloke et al., 1984; Bruce and Odin, 2001; CCME, 2015).

2.1.3 Toxicity

In soil culture, beryllium phytotoxicity is governed by the nature of the soil, particularly its cation-exchange capacity, and the pH of the soil solution (IPCS, 1990). Romney and Childress (1965) found that beryllium was strongly adsorbed by soils and bentonite, displacing barium, calcium, magnesium, and strontium. With increasing acidity, beryllium became more soluble and hence more toxic to plants. Williams and Le Riche (1968) concluded that the diminished phytotoxicity under alkaline conditions was the result of precipitation of beryllium as a phosphate salt, making it unavailable to plants. The response of plants to beryllium in soil did not cause a yield decrease in neutral pH soils but substantially decreased plant yields in quartz soils (Brown, K.W., G. B. Evans, Jr., B.D. Frentrup, eds., 1983; Irwin et al., 1997).

For bush beans *(Phaseolus vulgaris)* grown in an acidic nutrient solution at pH 5.3, an 88% yield reduction was observed at a concentration of 5 mg Be/litre (Romney et al., 1962). Effects were first observed on the roots, which turned brown and failed to resume normal elongation. The critical contents of beryllium resulting in a 50% decrease in yield were estimated to be about 3000 mg Be/kg dry weight and 6 mg Be/kg, respectively, in the roots and outer leaves of cabbage plants *(Brassica oleracea) (*Hara et al., 1977*).* Stunting of both roots and foliage was noted in soil cultures of beans, wheat, and ladino clover, but no chlorosis or mottling of the foliage occurred.

The mechanism underlying the phytotoxicity of beryllium involves its inhibitory effects on enzyme activity and on the uptake of essential mineral ions (Hoagland, 1952a, b; ICPS, 1990). Romney and Childress (1965) noted inhibition of ribulose 1.5-diphosphate carboxylase and phosphoenolpyruvate carboxylase at concentrations above 1 µmol beryllium nitrate/litre. The resulting interference with phosphorus metabolism is reflected by the enhanced phosphorus uptake observed in pea plants (Lebedeva, 1960) and increased phosphorus concentrations in the tissues of alfalfa, barley, pea, and lettuce plants (Romney and Childress, 1965). Conversely, uptake of calcium was reduced in all plant parts, particularly in the roots. Uptake of sodium, potassium, iron, and manganese was not influenced in these plants. However, in bush beans grown in nutrient solutions, leaf concentrations of these elements and of copper, zinc, boron, aluminum, silicon, molybdenum, strontium, and barium

were decreased by high beryllium concentrations (8 - 16 mg/litre as beryllium chloride) (Romney et al., 1980 as cited by ICPS, 1990).

Bidwell (1974) stated that beryllium is able to replace magnesium as an essential element in some fungi and partlyin tomatoes. Further, it apparently stimulates the growth of some plants (ryegrass and kale) while inhibiting others (bean). Stimulation seems to be dose-dependent, however. Williams and Le Riche (1968) observed a greater yield of kale at a beryllium concentration of 0.5 mg/litre when compared with the control though a reduced yield in kale grown in a nutrient culture solution containing more than 2 mg/litre of beryllium (as beryllium sulfate) was observed. Romney and Childress (1965) found that beryllium (as beryllium chloride) at levels greater than 2 ppm in nutrient solutions reduced the growth of alfalfa, lettuce, peas, and soybeans. Also, they reported that the yield of beans and wheat was reduced when beryllium occupied the equivalent of 4 percent of the cation-exchange capacity of soils. In a nutrient solution containing 16 ppm beryllium, plants showing toxicity symptoms of brown-root and stunted foliage had concentrations of beryllium in plant tops ranging from 27 ppm (dry weight) in alfalfa to 75 ppm in peas.

2.2 Terrestrial Invertebrates

2.2.1 Uptake, Metabolism, and Elimination

Information with regard to the uptake, metabolism and elimination of beryllium in invertebrate species is limited.

After 60 days of treatment *A.fulica* (terrestrial snail) fed a diet of rabbit pellets containing 10µg/mL beryllium had twice the amount of the metal in the digestive gland and six times the amount of the metal in the shell compared with those fed a diet containing beryllium supplemented with calcium (Ireland, 1986). However, the data suggests that relatively little of the beryllium available in the diet was deposited in the digestive gland or shell as evidenced by the high ratio of beryllium in faecal material relative to in the food consumed. The author suggests a potential inverse relationship between calcium consumption and beryllium absorption.

2.2.2 Bioaccumulation

A soil to invertebrate uptake bioaccumulation factor (based on dry weight) of 0.045 was developed for beryllium by Sample et al. (1998) and reported within the US EPA (2005) beryllium Eco SSL guidance.

2.2.3 Toxicity

The bounded no observed effect concentration (NOEC) and lowest observed effect concentration (LOEC) for juvenile production of *F.candida* (springtail) was 24 and 36 ppm beryllium sulfate in soil, respectively. The EC_{20} and EC_{50} values for juvenile production were 28 and 44 ppm, respectively.

ANOVA results of definitive cocoon production tests using actual measured concentrations of beryllium (as beryllium sulfate) in soil produced a bounded NOEC of 57 ppm and a bounded LOEC of 83 ppm. Beryllium did not significantly affect adult *F.candida* (springtail) survival up to 18 ppm (the NOEC) and was significantly reduced at 24 ppm (the LOEC) beryllium sulfate in soil (Phillips et al, 2002).

The bounded NOEC and LOEC for juvenile production of *E.crypticus (*potworm) was 43 and 57 ppm beryllium sulfate in soil, respectively. The EC_{20} and EC_{50} values for juvenile production were 45 and 52 ppm, respectively. Adult survival of *E.crypticus (*potworm) decreased by 58% in 100 ppm and juvenile production by 18% in 10 ppm beryllium sulfate soil treatments when compared with a negative control. No surviving adults or juveniles were recovered in 500 and 1,000 ppm treatments (Kuperman et al., 2006).

In a 21-day exposure, Simini et al. (2002) noted nominal concentrations of beryllium (as beryllium sulfate) in soil up to 100 ppm had a 100% survival rate for *E.fetida* (earthworm) adults. There was no survival at concentrations of 500 and 1000 ppm. The EC_{20} for toxicity of beryllium to *E.fetida* cocoon production was 52 ppm and the EC_{50} was 63 ppm. Results of the definitive adult survival tests showed a bounded NOEC of 83 ppm and a bounded LOEC of 110 ppm.

Ireland (1986) reported increased mortality and growth suppression in a terrestrial snail (*A.fulica)* fed 10 µg/ml beryllium in the diet containing sub-optimal calcium concentrations.

2.3 Terrestrial Livestock and Wildlife Species

2.3.1 Uptake, Metabolism, and Elimination

The respiratory tract, especially the lung, is the primary target of inhalation exposure in animals (Bruce and Odin, 2001). Significant absorption, approximately 20% of the initial lung burden, was noted via inhalation or intratracheal instillation of soluble beryllium salts; however, for sparingly soluble compounds (e.g., beryllium oxide), absorption is slower and less substantial. Studies in guinea-pigs and rats indicate that 40–50% of the inhaled soluble beryllium salts are retained in the respiratory tract (Delic, 1992; HSE, 1994). Animal studies have shown that clearance of soluble and sparingly soluble beryllium compounds is biphasic via both inhalation and intratracheal administration (Bruce and Odin, 2001) with an initial rapid phase (via mucocilary transport to the gastrointestinal tract) followed by a prolonged slow phase (via translocation to tracheobronchial lymph nodes, uptake by alveolar macrophages, and solubilization of beryllium) (Camner et al., 1977; Sanders et al., 1978; Delic, 1992; HSE, 1994). Rhoads and Sanders (1985) observed biphasic lung clearance in rats exposed for 30-180 min to beryllium oxide fired at 1,000°C. The first component accounted for 30% of the initial lung burden and had a half-life of 2.5 days. The second component had a half-life of 833 days. They found that whole-body clearance was uniphasic, with a half-life of

356 days. In the case of mice (Finch et al., 1998), lung clearance of beryllium was segregated into two discrete groups, with clearance half-times of 91–150 days (for 1.7- and 2.6-µg lung burden groups) or 360–400 days (for 12- and 34-µg lung burden groups). In an experiment with beagle dogs exposed for 5-42 min to beryllium oxide calcined at 500 or 1,000°C, Finch et al. (1990) found that the half-time for pulmonary clearance was 64 days for beryllium oxide calcined at 500°C and 240 days for beryllium oxide calcined at 1,000°C. Whole-body clearance was biphasic for the low-temperature calcined material, with 59% of the initial lung burden cleared with a half-life of 54 days and the half-life for the long-term component being more than 1,000 days. The amount of beryllium remaining in the lungs at any time after exposure is a function of the amount deposited and the rate of clearance, which depend in turn on the dose, size, and solubility of the specific beryllium particles inhaled (Bruce and Odin, 2001).

Following inhalation exposure, beryllium cleared from the lungs is distributed to the tracheobronchial lymph nodes and the skeleton, which is the ultimate site of beryllium storage (Stokinger et al., 1953; Clary et al., 1975; Sanders et al., 1975; Finch et al., 1990).

Beryllium is poorly absorbed from the gastrointestinal tract. Oral administration results in <1% absorption and storage (as reviewed by US EPA, 1991). Most of the beryllium taken up by the oral route passes through the gastrointestinal tract unabsorbed and is eliminated in the faeces (Bruce and Odin, 2001). Following oral exposure, beryllium accumulates mainly in bone, but is also found in the stomach, intestines, liver, kidney, spleen, mesenteric lymph nodes, and other soft tissues (Furchner et al., 1973; Morgareidge et al., 1975; Watanabe et al., 1985; LeFevre & Joel, 1986).

Beryllium is poorly absorbed through the skin. Only trace amounts of beryllium were absorbed through the tail skin of rats exposed to an aqueous solution of beryllium chloride (Petzow & Zorn, 1974 as cited in ASTDR, 2002).

Absorbed beryllium is eliminated primarily in the urine (Crowley et al., 1949; Scott et al., 1950; Furchner et al., 1973; Stiefel et al., 1980), whereas excretion of unabsorbed beryllium is primarily via the faecal route (Bruce and Odin, 2001).). In animal ingestion studies using radiolabelled beryllium chloride in rats, mice, dogs, and monkeys, the vast majority of the ingested dose was excreted in the faeces; in most studies, <1% of the administered radioactivity was excreted in the urine (Crowley et al., 1949; Furchner et al., 1973; LeFevre & Joel, 1986).

2.3.2 Bioaccumulation

There is no evidence of any significant bioaccumulation or biomagnification of beryllium in food chains (ATSDR, 2002; Fishbein 1981; Bruce and Odin, 2001; CCME, 2015).

2.3.3 Toxicity

No data were located regarding the toxicity of beryllium to terrestrial wildlife or livestock species.

With respect to repeated or continuous exposures to laboratory animals, the most marked effects (pneumonitis, fibrosis, proliferative lesions, metaplasia, and hyperplasia) were observed in the lungs of various animal species exposed to both soluble and sparingly soluble beryllium compounds. Studies on laboratory mammals showed that inhaled beryllium could be acutely toxic at concentrations as low as 0.15 mg beryllium/m^3 (4-h LC_{50} value in rats for beryllium sulfate; Venugopal and Luckey, 1977). In beagle dogs, single, acute, nose-only inhalation exposure to beryllium oxide calcined at 500 or 1000 °C induced granulomatous pneumonia, lymphocytic infiltration into the lung, and positive beryllium-specific lymphocyte proliferative responses *in vitro* (Bruce and Odin, 2001). Pulmonary effects (proliferative and inflammatory changes) following prolonged exposure to concentrations as low as 6 μg beryllium/m^3 in rats were identified in various studies.

In animal studies, inhalation exposure to beryllium produced significant increases in lung cancer in rats and monkeys (Schepers et al., 1959; Vorwald and Reeves, 1959; Reeves et al., 1967; Vorwald, 1968; Reeves & Deitch, 1969).

Ingested beryllium was acutely toxic at doses as low as 18 mg/kg body weight. A no observed adverse effect limit (NOAEL) of 0.15 mg beryllium/kg body weight per day was identified for chronic ingestion of beryllium in dogs based on lesions of the small intestine and bone marrow hypoplasia (Morgareidge et al., 1976). Chronic oral exposure of rats (0.4-43 mg/kg-day) and mice (1.2 mg/kg-day) to beryllium sulfate did not result in any adverse effects (Morgareidge et al., 1975, 1977; Schroeder and Mitchener, 1975a, b).

Rickets were observed in rats exposed to sparingly soluble beryllium carbonate (13-300 mg/kg-day) in the diet for 3–4 weeks, possibly due to decreased gastrointestinal absorption of phosphorus subsequent to formation of insoluble beryllium phosphate in the intestine (Guyatt et al., 1933; Kay & Skill, 1934). This is supported by the findings of Matsumoto et al. (1991) on rats fed beryllium carbonate (480 mg/kg/day) in the diet.

The oral studies in animals suggest that the gastrointestinal and the skeletal systems are target organs for beryllium. In dogs exposed to beryllium sulfate, the gastrointestinal tract is a sensitive target and lesions appear to be induced in the gut at doses less than those for bone marrow hypoplasia (Morgareidge *et al.*, 1976 in US EPA, 1998).

Both soluble and sparingly soluble compounds of beryllium have been shown to be skin sensitizers via various routes of exposure and in various animal species (Bruce and Odin, 2001).

The potential of beryllium to induce developmental and/or reproductive effects has not been adequately assessed (US EPA, 1998; Bruce and Odin, 2001). In the only oral exposure study examining reproductive or developmental end-points, beryllium did not affect fertility or pup survival, weight, or skeletal formation in dogs (Morgareidge et al., 1976).

3.0 DERIVATION OF ENVIRONMENTAL SOIL QUALITY GUIDELINES

3.1 Environmental Soil Quality Guidelines

Canadian Soil Quality Guidelines are derived for four different land uses: agricultural, residential/parkland, commercial and industrial. An additional land use, natural areas, is also used in Alberta (AEP, 2016).

All data for use in the following derivations have been screened for ecological relevance and are presented in the preceding sections. For the soil contact pathway, data were not selected from soils that are outside the typical conditions found in Canada (e.g. pH <4), or from studies that did not use soil or artificial soil, did not record soil texture and pH, did not use appropriate statistical analyses, did not use controls, or involved sewage sludge or mixtures of toxicants.

3.1.1 Soil Quality Guidelines for Soil Contact

Soil quality guidelines for soil contact (SQG_{SC}) are based on toxicological data for plants and soil invertebrates. The preferred approach is to use a weight of evidence method using EC_{25} or similar values; if the data do not meet the requirements for this method, then additional approaches using other data points can be applied, such as effects/ no effects data, lowest observed effects concentrations, and median effects.

The data requirements for the preferred weight of evidence approach include:

- At least 10 discrete data points from at least 3 studies.
- A minimum of 2 soil invertebrate and 2 crop/plant data points.

In some cases it is prudent to combine data points to eliminate redundancy by calculating the geometric mean of individual data points (CCME, 2006). For example, data points representing the same type of response in the same species under highly similar exposure conditions, or different responses that are known to be directly, causally connected should be combined. Consideration can also be given to combining data for different soil types – in general variations in toxicity due to

exposure conditions such as soil type are considered to be a valid part of the sensitivity distribution, but in some cases it may be appropriate to combine data points to prevent a significant bias of the sensitivity distribution to a single species. Where multiple response levels are available for the same species and response type (e.g. EC_{20} and EC_{50}), the value closest to the EC_{25} is used rather than combining the data points.

Plant toxicity data was collected from a study completed by Exova Laboratories (Edmonton, AB) in 2014. The experimental study consisted of three plant species with observations of four discrete end points providing 12 data end points. Plant toxicity studies were completed in a field collected soil. The Exova Laboratory study meets the minimum data requirements.

Invertebrate toxicity data was collected from a single study (Kuperman et al., 2006) which includes summarized results from two additional studies (Phillips et al., 2002; Simini et al., 2002) which were commissioned for the development of ecological soil screening levels (ECO-SSL) for the US EPA. Cumulatively, these study results provide one discrete data end point for three invertebrate species resulting in three data end points. The invertebrate studies were completed in a field-collected soil. The available invertebrate data does not meet the minimum requirements as described in CCME (2006) as at least 10 discrete data points from at least 3 studies are not available.

The combined plant and invertebrate data available for beryllium, however, allow for the utilization of the weight of evidence approach as the combined data satisfies the requirements in CCME (2006). Multiple response levels are available; EC_{25} values were used from the Exova plant toxicity study and EC_{20} values from Kuperman et al. (2006) as the values closest to EC_{25}. Inclusion of the Kuperman et al. (2006) data with EC values further from EC_{25} than the remaining data is conservative since the values from this study were all at the lower end of the resulting species sensitivity distribution. A total of 12 plant data points and 3 invertebrate endpoints were retained.

As specified by CCME (2006), the selected data were ranked and rank percentiles determined for each data point.

The resulting combined species sensitivity distribution is shown on Figure 1 below.

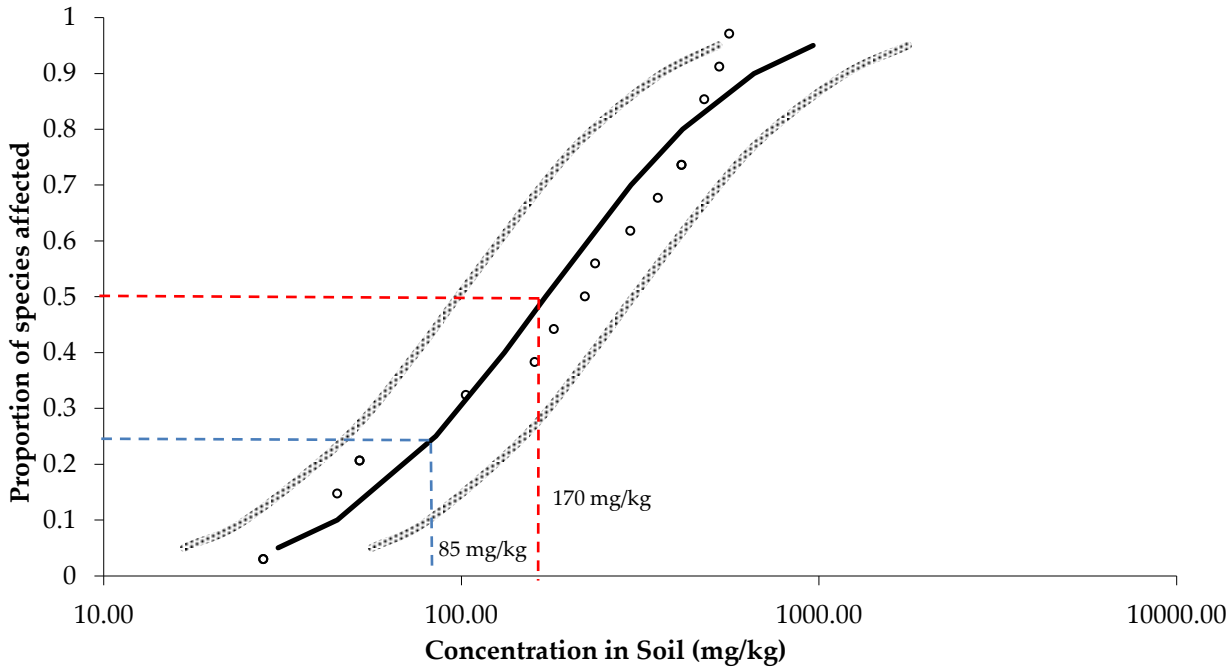

Figure 1: Species Sensitivity Distribution for Ecological Soil Contact

3.1.1.1 Guidelines for the Agricultural, Residential/Parkland Land Uses

The soil contact guidelines are calculated from the 25th percentile of the estimated species sensitivity distribution ($ESSD_{25}$) (Figure 1). The $ESSD_{25}$ has been calculated at 85 mg/kg.

The threshold effects concentration is then calculated as:

$$TEC = ESSD_{25}/UF$$

Where:

TEC	=	threshold effects concentration (mg/kg)
$ESSD_{25}$	=	estimated species distribution – 25th percentile (mg/kg)
UF	=	uncertainty factor (if needed)

An uncertainty factor is only applied if the data are borderline, such as if only the minimum number of studies is available, fewer than three taxonomic groups are represented, greater than 50% of either the plant or invertebrate toxicity data are in the lower 25th percentile of the combined distribution, short-term toxicity studies were used, or more than 50% of the data reflect low bioavailability conditions (CCME, 2006). None of these conditions apply, and therefore an uncertainty factor is not considered to be warranted.

The SQG_{SC} for the agricultural, residential/parkland and natural area land uses is set at the TEC, or 85 mg/kg.

3.1.1.2 Guidelines for the Commercial and Industrial Land Uses

The soil contact guidelines are calculated from the 50th percentile of the estimated species sensitivity distribution ($ESSD_{50}$) (Figure 1). The $ESSD_{50}$ has been calculated at 170 mg/kg.

The effects concentration - low is then calculated as:

$$ECL = ESSD_{50}$$

Where:

ECL	=	threshold effects concentration (mg/kg)
$ESSD_{50}$	=	estimated species distribution – 50th percentile (mg/kg)

An uncertainty factor is not normally applied to the ECL. The SQG_{SC} for the commercial and industrial land uses is set at the ECL, or 170 mg/kg.

3.1.1.3 Confidence Ranking for the Soil Contact Guideline

CCME (2006) uses a ranking system to indicate the confidence in the guideline, based on the method used and whether there were enough data to evaluate plants and invertebrates separately.

For beryllium, the preferred weight of evidence approach using EC_X data was used. The plant and invertebrate data were combined as there was insufficient invertebrate data to evaluate both groups separately. Therefore, a confidence ranking of 'B' is assigned.

3.1.2 Soil Quality Guidelines for Soil and Food Ingestion

Soil and food ingestion guidelines (SQG_I) are calculated for the agricultural and residential/parkland land uses to protect livestock and wildlife, including domestic animals.

The CCME (2006) process normally evaluates grazing herbivores on agricultural lands, although other species can be considered if identified as being particularly sensitive to the contamination. The first step is to identify the species most at threat based on oral toxicological data for grazing/foraging species. The minimum data requirements include at least two oral mammalian studies, only one of which can be a laboratory rodent study and at least one of which should reflect a grazing herbivore, and one oral avian study.

As discussed in 2.3.3, studies conducted on beryllium toxicity to livestock and wildlife species has been limited to laboratory mammalian studies, using primarily rodents. No grazing herbivore or avian studies were available for review. Based on an anticipated high ratio of exposure (based on soil/food ingestion rates and body weight) and smaller home range for rodents than larger grazing herbivores, these animals can be considered as species "most" threatened. Based on this both a rodent (meadow vole) and grazing herbivore (cattle) will be retained as representative receptors for guideline calculation.

3.1.2.1 Development of the Daily Threshold Effect Dose (DTED)

Several toxicity studies have been conducted using rodent species. Rodents can be considered as sensitive receptors due to a high exposure ratio and smaller home range than larger grazing herbivores. As such DTED values can be confidently established based solely upon rodent studies. The CCME (2006) protocol indicates that the DTED should be based on the lowest effects dose. Data reviewed by US EPA (2005) indicated that the lowest biologically relevant effects dose reported is 0.630 mg/kg-bw/d, based on body weight effects in rats.

From CCME (2006) an uncertainty factor between 1 and 5 can be applied to the DTED value for multiple reasons including extrapolation below the effects dose is required, acute lethal or sublethal data is used, only minimum data requirements are met or fewer than three taxonomic groups are available. Since the DTED is based on data from a species with relatively high exposure and since this value is very similar to the benchmark dose used to derive the human toxicity benchmark (CCME, 2015), no uncertainty factor is considered warranted.

The DTED is estimated then using the following equation (CCME, 2006):

$DTED_{1C}$ = lowest ED /UF

Where,

DTED = daily threshold effects dose (mg/kg bw/d)

ED = lowest effects dose (mg/kg bw/d)

UF = uncertainty factor (if needed)

The resulting DTED applied herein is 0.63 mg/kg bw/d.

3.1.2.2 Receptor Parameters

Cattle were retained as a representative receptor for livestock species based on a high ratio of exposure. A cattle body weight of 550 kg and soil ingestion rate of 0.747 kg/d have previously been

used for soil quality guideline derivation (CCME, 2006; ESRD, 2014). A cattle food ingestion rate of 12.29 kg/dw food/day was calculated using the allometric equation recommended by CCME (2006).

A meadow vole was retained as a representative receptor for wildlife species based on a high ratio of exposure. A vole with a body weight of 0.017 kg and soil ingestion rate of 0.000058 kg/d (ESRD, 2014) was used in guideline derivation. A food ingestion rate of 0.002 kg/d is calculated from reviewed literature (US EPA, 2005) and substantiated using the CCME (2006) allometric equation.

3.1.2.3 Bioavailability

There is no information on the relative bioavailability of beryllium in natural food/soil compared to bioavailability in the critical toxicity studies. A bioavailability factor of 1 is therefore assumed.

3.1.2.4 Bioconcentration Factors

The development of soil quality guidelines for herbivore food ingestion requires that a concentration of a substance in soil be established that will not lead to adverse effects on receptors via the ingestion of forage material. The bioconcentration factor (BCF) for beryllium was adopted from US EPA (2005); featuring 18 studies (soybean, collard, grass, oats) with 16 laboratory and 2 field based studies. The accumulated data was used to create a regression equation for beryllium uptake into plants. The adopted BCF value of 0.228 is based on the geometric mean of the solved regression equation for the included studies.

3.1.2.5 Calculation of the Soil Quality Guideline for Ingestion

The guideline for soil and food ingestion can be calculated for a primary consumer using the following equation (CCME, 2006):

$$SQG_I = \frac{0.75 \times DTED \times BW}{(SIR \times BF) + (FIR \times BCF)}$$

Where,

SQG_I	=	soil quality guideline for food and soil ingestion (mg/kg)
DTED	=	daily threshold effects dose of the primary consumer (mg/kg-bw_{1C}/d)
BW	=	body weight (kg)
SIR	=	soil ingestion rate (kg/d)
FIR	=	food ingestion rate (kg/d dry weight)
BF	=	bioavailability factor
BCF	=	bioconcentration factor (mg/kg plant per mg/kg soil)

The resulting SQG_I for protection of wildlife and livestock is 16 and 73 mg/kg, respectively. The final soil and food ingestion guideline is the value calculated for the protection of the most sensitive primary consumer. This guideline is considered provisional in the absence of wildlife, livestock and avian toxicity data.

4.0 REFERENCES

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