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Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Beryllium

PREFACE

This document is one of a series of preliminary assessments dealing with chemicals of potential concern in municipal sewage sludge. The purpose of these documents is to: (a) summarize the available data for the constituents of potential concern, (b) identify the key environmental pathways for each constituent related to a reuse and disposal option (based on hazard indices), and (c) evaluate the conditions under which such a pollutant may pose a hazard. Each document provides a scientific basis for making an initial determination of whether a pollutant, at levels currently observed in sludges, poses a likely hazard to human health or the environment when sludge is disposed of by any of several methods. These methods include landspreading on food chain or nonfood chain crops, distribution and marketing programs, landfilling, incineration and ocean disposal.

These documents are intended to serve as a rapid screening tool to narrow an initial list of pollutants to those of concern. If a significant hazard is indicated by this preliminary analysis, a more detailed assessment will be undertaken to better quantify the risk from this chemical and to derive criteria if warranted. If a hazard is shown to be unlikely, no further assessment will be conducted at this time; however, a reassessment will be conducted after initial regulations are finalized. In no case, however, will criteria be derived solely on the basis of information presented in this document.

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SECTION 1

INTRODUCTION

This preliminary data profile is one of a series of profiles dealing with chemical pollutants potentially of concern in municipal sewage sludges. Beryllium (Be) was initially identified as being of potential concern when sludge is incinerated.* This profile is a compilation of information that may be useful in determining whether Be poses an actual hazard to human health or the environment when sludge is disposed of by this method.

The focus of this document is the calculation of "preliminary hazard indices" for selected potential exposure pathways, as shown in Section 3. Each index illustrates the hazard that could result from movement of a pollutant by a given pathway to cause a given effect (e.g., sludge → air → human toxicity). The values and assumptions employed in these calculations tend to represent a reasonable "worst case"; analysis of error or uncertainty has been conducted to a limited degree. The resulting value in most cases is indexed to unity; i.e., values >1 may indicate a potential hazard, depending upon the assumptions of the calculation.

The data used for index calculation have been selected or estimated based on information presented in the "preliminary data profile", Section 4. Information in the profile is based on a compilation of the recent literature. An attempt has been made to fill out the profile outline to the greatest extent possible. However, since this is a preliminary analysis, the literature has not been exhaustively perused.

The "preliminary conclusions" drawn from each index in Section 3 are summarized in Section 2. The preliminary hazard indices will be used as a screening tool to determine which pollutants and pathways may pose a hazard. Where a potential hazard is indicated by interpretation of these indices, further analysis will include a more detailed examination of potential risks as well as an examination of site-specific factors. These more rigorous evaluations may change the preliminary conclusions presented in Section 2, which are based on a reasonable "worst case" analysis.

The preliminary hazard indices for selected exposure routes pertinent to incineration are included in this profile. The calculation formulae for these indices are shown in the Appendix. The indices are rounded to two significant figures.

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* Listings were determined by a series of expert workshops convened during March-May, 1984 by the Office of Water Regulations and Standards (OWRS) to discuss landspreading, landfilling, incineration, and ocean disposal, respectively, of municipal sewage sludge.

SECTION 2

PRELIMINARY CONCLUSIONS FOR BERYLLIUM IN MUNICIPAL SEWAGE SLUDGE

The following preliminary conclusions have been derived from the calculation of "preliminary hazard indices", which represent conservative or "worst case" analyses of hazard. The indices and their basis and interpretation are explained in Section 3. Their calculation formulae are shown in the Appendix.

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

Based on the recommendations of the experts at the OWRS meetings (April-May, 1984), an assessment of this reuse/disposal option is not being conducted at this time. The U.S. EPA reserves the right to conduct such an assessment for this option in the future.

II. LANDFILLING

Based on the recommendations of the experts at the OWRS meetings (April-May, 1984), an assessment of this reuse/disposal option is not being conducted at this time. The U.S. EPA reserves the right to conduct such an assessment for this option in the future.

III. INCINERATION

The level of Be contamination in the atmosphere is expected to increase slightly with the incineration of municipal sewage sludge. This is particularly evident when high Be concentration sludge is incinerated at high feed rates (see Index 1).

Also, the incineration of municipal sewage sludge appears to slightly increase the carcinogenic hazard associated with the inhalation of Be. The largest risk increase can be expected when high Be concentration sludge is incinerated at high feed rates with the worst level of stack emissions (see Index 2).

IV. OCEAN DISPOSAL

Based on the recommendations of the experts at the OWRS meetings (April-May, 1984), an assessment of this reuse/disposal option is not being conducted at this time. The U.S. EPA reserves the right to conduct such an assessment for this option in the future.

SECTION 3

PRELIMINARY HAZARD INDICES FOR BERYLLIUM IN MUNICIPAL SEWAGE SLUDGE

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

Based on the recommendations of the experts at the OWRS meetings (April-May, 1984), an assessment of this reuse/disposal option is not being conducted at this time. The U.S. EPA reserves the right to conduct such an assessment for this option in the future.

II. LANDFILLING

Based on the recommendations of the experts at the OWRS meetings (April-May, 1984), an assessment of this reuse/disposal option is not being conducted at this time. The U.S. EPA reserves the right to conduct such an assessment for this option in the future.

III. INCINERATION

A. Index of Air Concentration Increment Resulting from Incinerator Emissions (Index 1)

1. **Explanation** - Shows the degree of elevation of the pollutant concentration in the air due to the incineration of sludge. An input sludge with thermal properties defined by the energy parameter (EP) was analyzed using the BURN model (Camp Dresser and McKee, Inc. (CDM), 1984). This model uses the thermodynamic and mass balance relationships appropriate for multiple hearth incinerators to relate the input sludge characteristics to the stack gas parameters. Dilution and dispersion of these stack gas releases were described by the U.S. EPA's Industrial Source Complex Long-Term (ISCLT) dispersion model from which normalized annual ground level concentrations were predicted (U.S. EPA, 1979). The predicted pollutant concentration can then be compared to a ground level concentration used to assess risk.

2. **Assumptions/Limitations** - The fluidized bed incinerator was not chosen due to a paucity of available data. Gradual plume rise, stack tip downwash, and building wake effects are appropriate for describing plume behavior. Maximum hourly impact values can be translated into annual average values.

3. **Data Used and Rationale**

   a. **Coefficient to correct for mass and time units (C) =** 2.78×10^{-7} hr/sec x g/mg

b. **Sludge feed rate (DS)**

i. **Typical** = 2660 kg/hr (dry solids input)

A feed rate of 2660 kg/hr DW represents an average dewatered sludge feed rate into the furnace. This feed rate would serve a community of approximately 400,000 people. This rate was incorporated into the U.S. EPA-ISCLT model based on the following input data:

EP = 360 lb H_2O/mm BTU
Combustion zone temperature - 1400°F
Solids content - 28%
Stack height - 20 m
Exit gas velocity - 20 m/s
Exit gas temperature - 356.9°K (183°F)
Stack diameter - 0.60 m

ii. **Worst** = 10,000 kg/hr (dry solids input)

A feed rate of 10,000 kg/hr DW represents a higher feed rate and would serve a major U.S. city. This rate was incorporated into the U.S. EPA-ISCLT model based on the following input data:

EP = 392 lb H_2O/mm BTU
Combustion zone temperature - 1400°F
Solids content - 26.6%
Stack height - 10 m
Exit gas velocity - 10 m/s
Exit gas temperature - 313.8°K (105°F)
Stack diameter - 0.80 m

c. **Sludge concentration of pollutant (SC)**

Typical	0.313 mg/kg DW
Worst	1.168 mg/kg DW

Median and 95th percentile (typical and worst) were statistically derived from data presented by a survey of sludge concentration of 40 publicly-owned treatment works (POTWs) (U.S. EPA, 1982). (See Section 4, p. 4-1.)

d. **Fraction of pollutant emitted through stack (FM)**

Typical	0.01 (unitless)
Worst	0.03 (unitless)

Emission estimates may vary considerably between sources; therefore, the values used are based on a U.S. EPA 10-city incineration study (Farrell and

Wall, 1981). Where data were not available from the EPA study, a more recent report which thoroughly researched heavy metal emissions was utilized (CDM, 1983).

e. **Dispersion parameter for estimating maximum annual ground level concentration (DP)**

Typical 3.4 $\mu g/m^3$
Worst 16.0 $\mu g/m^3$

The dispersion parameter is derived from the U.S. EPA-ISCLT short-stack model.

f. **Background concentration of pollutant in urban air (BA) = 0.00025 $\mu g/m^3$**

Values for 12 cities with populations >500,000 were averaged. The range of background concentrations for Be was from 0.0001 to 0.0005 $\mu g/m^3$ (U.S. EPA, 1978). (See Section 4, p. 4-3.)

4. **Index 1 Values**

Fraction of Pollutant Emitted Through Stack	Sludge Concentration	Sludge Feed Rate (kg/hr DW)[a] 0	2660	10,000
Typical	Typical	1.0	1.0	1.6
	Worst	1.0	1.1	3.1
Worst	Typical	1.0	1.1	2.7
	Worst	1.0	1.4	7.2

[a]The typical (3.4 $\mu g/m^3$) and worst (16.0 $\mu g/m^3$) dispersion parameters will always correspond, respectively, to the typical (2660 kg/hr DW) and worst (10,000 kg/hr DW) sludge feed rates.

5. **Value Interpretation** - Value equals factor by which expected air concentration exceeds background levels due to incinerator emissions.

6. **Preliminary Conclusion** - The level of Be contamination in the atmosphere is expected to increase slightly with the incineration of municipal sewage sludge. This is particularly evident when high Be concentration sludge is incinerated at high feed rates.

B. **Index of Human Cancer Risk Resulting from Inhalation of Incinerator Emissions (Index 2)**

1. **Explanation** - Shows the increase in human intake expected to result from the incineration of sludge. Ground level concentrations for carcinogens typically were developed based upon assessments published by the U.S. EPA Carcinogen Assessment Group (CAG). These ambient concentrations reflect a dose level which, for a lifetime exposure, increases the risk of cancer by 10^{-6}.

2. **Assumptions/Limitations** - The exposed population is assumed to reside within the impacted area for 24 hours/day. A respiratory volume of 20 m^3/day is assumed over a 70-year lifetime.

3. **Data Used and Rationale**

   a. **Index of air concentration increment resulting from incinerator emissions (Index 1)**

      See Section 3, p. 3-3.

   b. **Background concentration of pollutant in urban air (BA)** = 0.00025 $\mu g/m^3$

      See Section 3, p. 3-3.

   c. **Cancer potency** = 2.6 $(mg/kg/day)^{-1}$

      The cancer potency value was derived from a study of carcinogenic effects produced by occupational inhalation of Be (U.S. EPA, 1984). (See Section 4, p. 4-5.)

   d. **Exposure criterion (EC)** = 1.35×10^{-3} $\mu g/m^3$

      A lifetime exposure level which would result in a 10^{-6} cancer risk was selected as ground level concentration against which incinerator emissions are compared. The risk estimates developed by CAG are defined as the lifetime incremental cancer risk in a hypothetical population exposed continuously throughout their lifetime to the stated concentration of the carcinogenic agent. The exposure criterion is calculated using the following formula:

$$EC = \frac{10^{-6} \times 10^{3}\ \mu g/mg \times 70\ kg}{\text{Cancer potency} \times 20\ m^3/day}$$

4. **Index 2 Values**

Fraction of Pollutant Emitted Through Stack	Sludge Concentration	Sludge Feed Rate (kg/hr DW)[a] 0	2660	10,000
Typical	Typical	0.18	0.19	0.29
	Worst	0.18	0.21	0.57
Worst	Typical	0.18	0.20	0.49
	Worst	0.18	0.25	1.3

[a]The typical (3.4 $\mu g/m^3$) and worst (16.0 $\mu g/m^3$) dispersion parameters will always correspond, respectively, to the typical (2660 kg/hr DW) and worst (10,000 kg/hr DW) sludge feed rates.

5. **Value Interpretation** - Value > 1 indicates a potential increase in cancer risk of > 10^{-6} (1 per 1,000,000). Comparison with the null index value at 0 kg/hr DW indicates the degree to which any hazard is due to sludge incineration, as opposed to background urban air concentration.

6. **Preliminary Conclusion** - The incineration of municipal sewage sludge appears to slightly increase the carcinogenic hazard associated with the inhalation of Be. The largest risk increase can be expected when high Be concentration sludge is incinerated at high feed rates with the worst level of stack emissions.

IV. OCEAN DISPOSAL

Based on the recommendations of the experts at the OWRS meetings (April-May, 1984), an assessment of this reuse/disposal option is not being conducted at this time. The U.S. EPA reserves the right to conduct such an assessment for this option in the future.

SECTION 4

PRELIMINARY DATA PROFILE FOR BERYLLIUM IN MUNICIPAL SEWAGE SLUDGE

I. OCCURRENCE

Be is a moderately rare element, existing naturally only in mineral forms. Commercially, it is used as the metal (35%), as beryllium-copper alloys (50%), as other alloys (10%), and as beryllium oxide ceramic products (5%). The primary non-occupational source of Be exposure is coal combustion. According to 1968 data, an annual total of 148 metric tons of Be is released to the U.S. environment from a variety of sources with coal combustion accounting for 85% of the emissions.

U.S. EPA, 1978 (p. 1,5)

A. Sludge

1. Frequency of Detection

Be was detected in 98 of 439 samples (22%) from 40 POTWS.

U.S. EPA, 1982 (p. 41)

Be was detected in 52 of 81 samples (64%) from 10 POTWS.

U.S. EPA, 1982 (p. 49)

2. Concentration

In 23 POTWs reporting analytical results for Be, the following were obtained:

Median	0.313 µg/g DW
Mean	0.503 µg/g DW
Geom. Mean	0.309 µg/g DW
95th Percentile	1.168 µg/g DW

Values derived by statistical analysis of U.S. EPA, 1982

A range of Be concentration was reported as <4 to <15 µg/g (DW) in sludges of 15 U.S. cities (all values reported as "less than").

Furr et al., 1976 (p. 684)

B. Soil - Unpolluted

1. Frequency of Detection

"Due to its prevalence in rocks, beryllium occurs in most soils."

U.S. EPA, 1978 (p. 175)

2. Concentration

	Average (µg/g)	Range (µg/g)	
Contiguous United States	1	1-7	U.S. EPA, 1978 (p. 176)
OH, WV, GA, MD, NC, SC (15 samples)	0.37	0.13-0.88	U.S. EPA, 1978 (p. 176)
Indiana loesses	--	6-8	U.S. EPA, 1978 (p. 180)

C. Water - Unpolluted

1. Frequency of Detection

"Be is almost non-existent in natural waters." — U.S. EPA, 1978 (p. 180-181)

Be was detected in 85 out of 1,577 drinking water samples (5.4%) throughout the United States — U.S. EPA, 1980a (p. C-1)

2. Concentration

a. Freshwater

Generally <1 µg/L — U.S. EPA, 1978 (p. 180-181)

Atchafalyaa River, LA: 0.1 to 1 µg/L; Delaware and Hudson Rivers: 0.1 µg/L — U.S. EPA, 1978 (p. 180-181)

b. Seawater

Generally: <0.0006 µg/L
Pacific Ocean: 0.00057 µg/L — U.S. EPA, 1978 (p. 180-181)

c. Drinking water

In 1,500 U.S. raw and finished water samples -
average: 0.19 µg/L
range: 0.01 to 1.22 µg/L
(1.22 µg/L thought to be the result of mine drainages) — U.S. EPA, 1978 (p. 180-181)

D. Air

1. Frequency of detection

"Beryllium is generally found in the atmosphere in minute concentrations."	U.S. EPA, 1978 (p. 181)
"...Undetectable in most of the over 100 cities sampled by the National Air Surveillance Network	U.S. EPA, 1978 (p. 181)

2. Concentration

Averages of up to 0.0005 $\mu g/m^3$ were found in a survey including over 30 metropolitan areas in the U.S. Rural and suburban areas averaged 0.0001 to 0.0002 $\mu g/m^3$	U.S. EPA, 1978 (p. 182)
Be content of the atmosphere is less than 0.0001 mg/m^3	Bowen, 1966 in U.S. EPA, 1978 (p. 181)
Maximum of 0.003 $\mu g/m^3$ of Be in air of more than 30 metropolitan areas	Durocher, 1969 in U.S. EPA, 1978 (p. 181)
Average Be concentrations in urban area listed below range from 0.0001 to 0.0005; mean = 0.00025	Durocher, 1969 in U.S. EPA, 1978 (p. 182)

AVERAGE BERYLLIUM CONCENTRATIONS IN URBAN AND RURAL AREAS

Area	Concentration ($\mu g/m^3$)
<u>Cities with a population of over 2,000,000</u>	
Los Angeles	0.0001
Detroit	0.0004
Philadelphia	0.0005
Chicago	0.0002
New York	0.0003
<u>Cities with populations between 500,000 and 2,000,000</u>	
Cincinnati	0.0002
Kansas City	0.0003
Portland	0.0003
Atlanta	0.0002
Houston	0.0002
San Francisco	0.0001
Minneapolis	0.0002

Rural or Suburban

Boonsboro, Maryland	0.0001
Salt Lake City	0.0001
Atlanta	0.0002
Cincinnati	0.0001
Portland	0.0001

Source: Adapted from Chambers et al., 1955 (cited in Durocher, 1969 (p. 42). Taken from U.S. EPA, 1978, Table 7 to 11 (p. 182).

0.003 $\mu g/m^3$ of Be in suspended particulate samples from Houston, Denver, and Louisville. Trace quantities (<0.003 $\mu g/m^3$) in Chattanooga, Chicago, Cincinnati, E. Chicago, Minneapolis, Paulsboro, New Orleans, New York, Philadelphia, and Washington.	Tabor and Warren, 1958 in U.S. EPA, 1978 (p. 181)

E. Food

1. Total Average Intake

Data not immediately available.

2. Concentration

No U.S. data available

New South Wales, Australia: <0.01 to 0.10 µg/g in fresh ash weight (excluding fish/shellfish) West Germany: 0.12 to 0.3 µg/g	U.S. EPA, 1978 (p. 185)

II. HUMAN EFFECTS

A. Ingestion

1. Carcinogenicity

a. Qualitative Assessment

No data was found to support carcinogenic effects in humans due to oral ingestion.

b. Potency

Insufficient data available for derivation.	U.S. EPA, 1984

c. Effects

No carcinogenic effects have been clearly observed.	U.S. EPA, 1984 (p. 7-22)

2. Chronic Toxicity

Data not immediately available.

3. Absorption Factor

Data not available for humans. For an oral dose in mice, rats, monkeys, and dogs, there was <1% absorption through gut.	U.S. EPA, 1984 (p. 2-2)

4. Existing Regulations

No data found that regulates the human ingestion of Be.

B. Inhalation

1. Carcinogenicity

a. Qualitative Assessment

Equivocal effects have been observed in humans due to occupational inhalation of Be. The Carcinogen Assessment Group has given Be an IARC rating of Group 2: "probably carcinogenic to humans."	U.S. EPA, 1984 (p. 2-7)

b. Potency

The cancer potency that relates to the inhalation of Be is 2.6 $(mg/kg/day)^{-1}$.	U.S. EPA, 1984 (p. 7-66)

c. Effects

Lung and bone cancer have been attributed to the inhalation of Be.	U.S. EPA, 1984 (p. 7-73)

2. Chronic Toxicity

Data not presented because cancer potency will be used to assess hazard.

3. **Absorption Factor**

No data for humans. Rats absorbed 18% of inhalation dosage in 147 days.	U.S. EPA, 1978 (p. 103)

4. **Existing Regulations**

ACGIH threshold limit values 2.0 $\mu g/m^3$ (8-hour TWA) 5.0 $\mu g/m^3$ (ceiling concentration)	ACGIH, 1977
NIOSH threshold limit values 1.0 $\mu g/m^3$ (8-hour TWA) 5.0 $\mu g/m^3$ (ceiling concentration)	NIOSH, 1972

III. PLANT EFFECTS

A. Phytotoxicity

See Table 4-1.

In order to affect plants, Be must be in soluble form. Phytotoxic effects increase as pH decreases.	U.S. EPA, 1978 (p. 80, 82)

B. Uptake

See Table 4-2.

IV. DOMESTIC ANIMAL AND WILDLIFE EFFECTS

A. Toxicity

See Table 4-3.

Be has been demonstrated to be a carcinogen and a toxin when injected or inhaled at sufficient levels.	U.S. EPA, 1980a (C-8) Groth, 1980 (p. 56)
Be has been shown to be carcinogenic in rabbits, rats, and monkeys via intravenous injection, inhalation, and intratracheal instillation.	U.S. EPA, 1980b (p. 3)

B. Uptake

In cows, most of the absorbed Be accumulates in the liver, kidney, and skeletal system.	U.S. EPA, 1978 (p. 97)

"Be does not biomagnify within food chains. Be ingested by higher animals is not absorbed through the digestive tract but is readily excreted." — U.S. EPA, 1978 (p. 185)

V. AQUATIC LIFE EFFECTS

Data not immediately available.

VI. SOIL BIOTA EFFECTS

A. Toxicity

Under normal pH and magnesium conditions, Be inhibits the growth of microorganisms. Concentrations of 2 µg/L reduce growth by over 50%. — U.S. EPA, 1978 (p. 78)

B. Uptake

Data not immediately available.

VII. PHYSICOCHEMICAL DATA FOR ESTIMATING FATE AND TRANSPORT

Atomic weight: 9.01218
Density: 1.8477 ± 0.0007 g/cm^3, 25°C
Melting point: 1287 to 1292°C
Boiling point: 2970°C

— U.S. EPA, 1978 (p. 12)

Very resistant to oxidation in air

Most common Be compounds are readily soluble in water. — U.S. EPA, 1980a (p. A-1)

TABLE 4-1. PHYTOTOXICITY OF BERYLLIUM

Plant/Tissue	Chemical Form Applied	Growth Medium	Control Tissue Concentration (µg/g DW)	Experimental[a] Soil Concentration (µg/g DW)	Experimental Application Rate (kg/ha)	Experimental Tissue Concentration (µg/g DW)	Effect	References
Alfalfa	Be (soluble)	nutrient medium	NR[b]	2.0	--	NR	Roots and shoots affected. Poliage turns dark green	Romney and Childress, 1965 (p. 210)
Barley	Be (soluble)	nutrient medium	NR	2.0	--	NR	Stunted roots and leaves; profuse secondary root growth	Romney and Childress, 1965 (p. 210)
Lettuce	Be (soluble)	nutrient medium	NR	2.0	--	NR	Stunted brown roots; growth depression; profuse secondary root growth	Romney and Childress, 1965 (p. 210)
Green Pea	Be (soluble)	nutrient medium	NR	2.0	--	NR	Stunted brown roots; growth depression; profuse secondary root growth	Romney and Childress, 1965 (p. 210)
Soybean	Be (soluble)	nutrient medium	NR	2.0	--	NR	Stunted brown roots; growth depression; profuse secondary root growth	Yopp et al., 1974 (p. 44-45)
Tomato	Be (soluble)	nutrient medium	NR	2.0	--	NR	Stunted brown roots; growth depression; profuse secondary root growth	Yopp et al., 1974 (p. 44-45)

Table 4-1. (continued)

Plant/Tissue	Chemical Form Applied	Growth Medium	Control Tissue Concentration (µg/g DW)	Experimental[a] Soil Concentration (µg/g DW)	Experimental Application Rate (kg/ha)	Experimental Tissue Concentration (µg/g DW)	Effect	References
Wheat	Be (soluble)	nutrient medium	NR	2.0	--	NR	Stunted brown roots and leaves which turn dark green as dwarfing intensifies	Yopp et al., 1974 (p. 44-45)
Tomato	Be (soluble)	nutrient medium	NR	0.5	--	NR	General growth depression	Yopp et al., 1974 (p. 44-45)
Bush bean	Be (soluble)	nutrient medium	NR	0.5	--	NR	Stunted brown roots; secondary	Yopp et al., 1974 (p. 44-45) root growth
Corn	Be (soluble)	soil	NR	1.0	--	NR	General growth retardation	Yopp et al., 1974 (p. 44-45)
Bean/plant	$BeCO_3$, BeO[c]	soil	NR	>10	--	NR	No effect	U.S. EPA, 1978 (p. 80)
Bean/plant	$Be(NO_3)_2$[d]	soil	NR	10	--	NR	Inhibited growth $BeSO_4$(p. 80)	U.S. EPA, 1978
Kale/plant	Be (soluble)	pH 5.8	NR	40.0	--	NR	14% reduction yield of large plants; 44% reduction yield of seedling (NS)	U.S. EPA, 1978 (p. 82)
Kale/plant	Be (soluble)	pH 7.5	NR	40		NR	2% reduction of yield of large reduction in seedlings (NS)	U.S. EPA, 1978 (p. 82)

TABLE 4-1. (continued)

Plant/Tissue	Chemical Form Applied	Growth Medium	Control Tissue Concentration (µg/g DW)	Experimental[a] Soil Concentration (µg/g DW)	Experimental Application Rate (kg/ha)	Experimental Tissue Concentration (µg/g DW)	Effect	References
Kale/plant	Be (soluble)	pH 8.0	NR	40	--	NR	2% increased yield of large plants; 22% increased yield in seedlings	U.S. EPA, 1978 (p. 82)

[a]All values listed represent minimum phytotoxic concentrations.
[b]NR = Not reported.
[c]Insoluble forms of Be.
[d]Soluble forms of Be.

TABLE 4-2. UPTAKE OF BERYLLIUM BY PLANTS

Plant/Tissue	Growth Medium	Chemical Form Applied	Soil Concentration(N)[a] (µg/g)	Tissue Concentration (µg/g)	Uptake Slope[b]	References
Alfalfa/leaf & stem	nutrient solution	Be (soluble)	0-16 (4)	0-27.6	1.79	U.S. EPA, 1978 (p. 81)
Barley/foliage	nutrient solution	Be (soluble)	0-16 (5)	0-68	3.22	U.S. EPA, 1978 (p. 81)
Lettuce/foliage	nutrient solution	Be (soluble)	0-16 (5)	0-55	4.15	U.S. EPA, 1978 (p. 81)
Pea/leaf & stem	nutrient solution	Be (soluble)	0-16 (5)	0-75.3	4.16	U.S. EPA, 1978 (p. 81)
Barley/roots	nutrient solution	Be (soluble)	0-16 (5)	0-2,030.0	127.27	U.S. EPA, 1978 (p. 81)
Bush beans/roots	nutrient solution	Be (soluble)	0-5 (6)	0-1,076.0	273.08	U.S. EPA, 1978 (p. 81)
Bush bean/stems	nutrient solution	Be (soluble)	0-5 (6)	0-24.0	5.88	U.S. EPA, 1978 (p. 81)
Bush beans/leaves	nutrient solution	Be (soluble)	0-6 (6)	0-70.0	15.00	U.S. EPA, 1978 (p. 81)
Bush beans/fruit	nutrient solution	Be (soluble)	0-6 (6)	0-6.0	1.33	U.S. EPA, 1978 (p. 81)

[a] N = Number of soil concentrations.
[b] Uptake slope y/x: x = tissue concentration; y = soil concentration.

TABLE 4-3. TOXICITY OF BERYLLIUM TO DOMESTIC ANIMALS AND WILDLIFE

Species (N)[a]	Chemical Form	Food Concentration (µg/g)	Water Concentration (mg/L)	Daily Intake (mg/kg)	Duration	Effects	References
Rats	$BeCl_2$	--	--	9.7	--	LD_{50}[b]	U.S. EPA, 1980a (p. C-8)
Rats	$BeCO_3$	20,000	--	--	several weeks	Survived several weeks	U.S. EPA, 1980a (p. C-8)
Rats	$BeCO_3$	--	--	0.03 g/day tot.	50 days	Survived at least 50 days	U.S. EPA, 1980a (p. C-8)
Rats/Mice	$BeSO_4$	--	5	--	lifetime	No change in growth rate, longevity, tumors	Schroeder and Mitchener, 1975a; 1975b (p. 422-425; 454-456)
Rats	Be (soluble)	5-500	--	--	2 years	Significant increase in lung sarcomas in 5 and 50 dose groups, not 500	U.S. EPA, 1980a (p. C-26).
Rats	$BeSO_4$	--	--	1	2 years	No effect	NAS, 1977 (p. 233)
Dog (4)	$BeSO_4$	--	--	10	19 mos.	No effect	

[a] N = Number of experimental animals when reported.
[b] Lethal dose 50; dose of a substance which is fatal to 50 percent of the test animals.

SECTION 5

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APPENDIX

PRELIMINARY HAZARD INDEX CALCULATIONS FOR BERYLLIUM IN MUNICIPAL SEWAGE SLUDGE

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

Based on the recommendations of the experts at the OWRS meetings (April-May, 1984), an assessment of this reuse/disposal option is not being conducted at this time. The U.S. EPA reserves the right to conduct such an assessment for this option in the future.

II. LANDFILLING

Based on the recommendations of the experts at the OWRS meetings (April-May, 1984), an assessment of this reuse/disposal option is not being conducted at this time. The U.S. EPA reserves the right to conduct such an assessment for this option in the future.

III. INCINERATION

A. Index of Air Concentration Increment Resulting from Incinerator Emissions (Index 1)

1. Formula

$$\text{Index 1} = \frac{(C \times DS \times SC \times FM \times DP) + BA}{BA}$$

where:

- C = Coefficient to correct for mass and time units (hr/sec x g/mg)
- DS = Sludge feed rate (kg/hr DW)
- SC = Sludge concentration of pollutant (mg/kg DW)
- FM = Fraction of pollutant emitted through stack (unitless)
- DP = Dispersion parameter for estimating maximum annual ground level concentration ($\mu g/m^3$)
- BA = Background concentration of pollutant in urban air ($\mu g/m^3$)

2. Sample Calculation

$$1.031478 = [(2.78 \times 10^{-7} \text{ hr/sec} \times \text{g/mg} \times 2660 \text{ kg/hr DW} \times 0.313 \text{ mg/kg DW} \times 0.01 \times 3.4 \ \mu g/m^3) + 0.00025 \ \mu g/m^3] \div 0.00025 \ \mu g/m^3$$

B. **Index of Human Cancer Risk Resulting from Inhalation of Incinerator Emissions (Index 2)**

1. **Formula**

$$\text{Index 2} = \frac{[(I_1 - 1) \times BA] + BA}{EC}$$

where:

I_1 = Index 1 = Index of air concentration increment resulting from incinerator emissions (unitless)
BA = Background concentration of pollutant in urban air ($\mu g/m^3$)
EC = Exposure criterion ($\mu g/m^3$)

2. **Sample Calculation**

$$0.19101447 = \frac{[(1.031478 - 1) \times 0.00025\ \mu g/m^3] + 0.00025\ \mu g/m^3}{0.00135\ \mu g/m^3}$$

IV. OCEAN DISPOSAL

Based on the recommendations of the experts at the OWRS meetings (April-May, 1984), an assessment of this reuse/disposal option is not being conducted at this time. The U.S. EPA reserves the right to conduct such an assessment for this option in the future.