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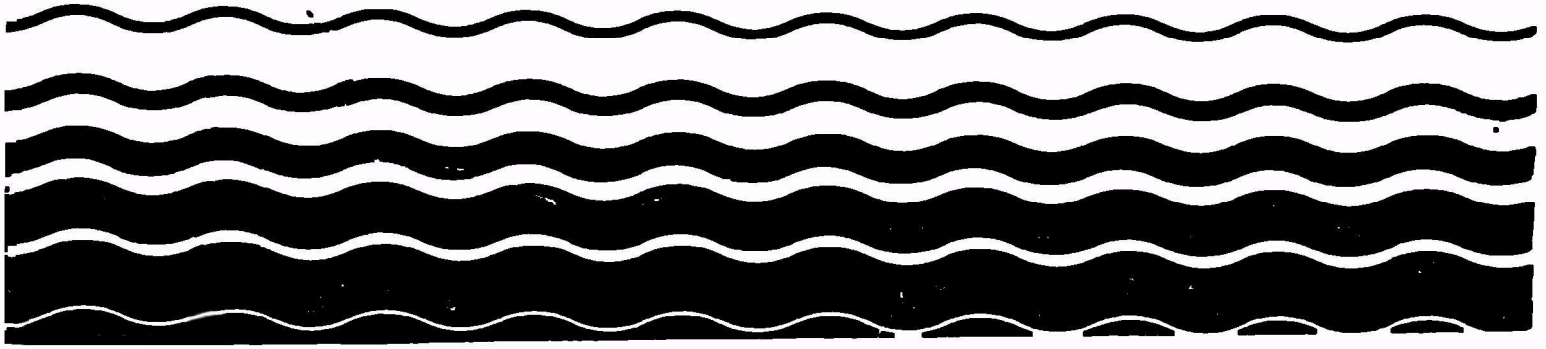
Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Fluoride



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. Fluoride was initially identified as being of potential concern when sludge is landspread (including distribution and marketing).* This profile is a compilation of information that may be useful in determining whether fluoride 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 → soil → plant uptake → animal uptake → 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 landspreading and distribution and marketing practices 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 FLUORIDE 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

A. Effect on Soil Concentration of Fluoride

Soil concentrations of fluoride are not expected to change significantly due to landspreading of sludge. A high application of sludge containing a typical concentration of fluoride may increase the soil concentration due to dilution, and a high application of sludge containing a high concentration of fluoride may increase the soil concentration by 30 percent (see Index 1).

B. Effect on Soil Biota and Predators of Soil Biota

Conclusions were not drawn because index values could not be calculated due to lack of data (see Indices 2 and 3).

C. Effect on Plants and Plant Tissue Concentration

Fluoride in sludge-amended soil is not expected to pose a hazard to plants (see Index 4). The concentrations of fluoride in plants consumed by animals and humans are not expected to increase as a result of landspreading sludge, except when sludge with a high fluoride concentration is applied at high rates (see Index 5). The maximum increase in fluoride concentration predicted for plants in the human and animal diet will not be precluded by phytotoxicity (see Index 6).

D. Effect on Herbivorous Animals

Landspreading of sludge is not expected to pose a toxic hazard from fluoride to grazing animals that feed on plants grown on sludge-amended soil (see Index 7), or that incidentally ingest sludge-amended soil (see Index 8).

E. Effect on Humans

Landspreading of sludge is not expected to pose a health hazard from fluoride to humans who consume plants grown on sludge-amended soil (see Index 9); ingest animal products derived from animals fed crops grown on sludge-amended soil (see Index 10); or consume animal products derived from animals ingesting sludge-amended soil (see Index 11).

Ingestion of sludge-amended soil is not expected to pose a human health hazard due to fluoride, except possibly for toddlers who ingest pure sludge containing a high concentration of fluoride (see Index 12). An aggregate human health hazard due to fluoride is not expected to occur as a result of landspreading sludge (see Index 13).

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

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.

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 FLUORIDE IN MUNICIPAL SEWAGE SLUDGE

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

A. Effect on Soil Concentration of Fluoride

1. Index of Soil Concentration Increment (Index 1)

a. **Explanation** - Shows degree of elevation of pollutant concentration in soil to which sludge is applied. Calculated for sludges with typical (median if available) and worst (95th percentile if available) pollutant concentrations, respectively, for each of four sludge loadings. Applications (as dry matter) are chosen and explained as follows:

0 mt/ha	No sludge applied. Shown for all indices for purposes of comparison, to distinguish hazard posed by sludge from pre-existing hazard posed by background levels or other sources of the pollutant.
5 mt/ha	Sustainable yearly agronomic application; i.e., loading typical of agricultural practice, supplying ~50 kg available nitrogen per hectare.
50 mt/ha	Higher application as may be used on public lands, reclaimed areas or home gardens.
500 mt/ha	Cumulative loading after years of application.

b. **Assumptions/Limitations** - Assumes pollutant is distributed and retained within the upper 15 cm of soil (i.e., the plow layer), which has an approximate mass (dry matter) of 2×10^3 mt/ha.

c. **Data Used and Rationale**

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

Typical	86.4 µg/g DW
Worst	738.7 µg/g DW

The typical and worse sludge concentrations are the median and 95th perentile values statistically derived from sludge concentration data

from a survey of 40 publicly-owned treatment works (POTWs) (U.S. EPA, 1982). (See Section 4, p. 4-1.)

ii. **Background concentration of pollutant in soil (BS) = 292 µg/g DW**

The background soil concentration for fluoride, 292 µg/g, is the mean concentration for soils 0 to 12 inches in depth (Robinson and Edgington, 1946, as cited in National Academy of Sciences (NAS), 1971). The mean represents concentrations from 30 samples throughout the U.S. ranging from 20 µg/g to 1620 µg/g. In the same study, concentrations of fluoride in soil from 0 to 3 inches depth ranged from 20 to 500 µg/g with a mean of 190 µg/g. Since fluoride concentration generally increases with depth, the concentrations for 12 inches was selected conservatively as a representative concentration. This selected value falls within the normal fluoride concentration range of 200 to 300 µg/g for mineral soils (U.S. EPA, 1980). (See Section 4, p. 4-1.)

d. **Index 1 Values**

Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Typical	1	1.0	0.98	0.86
Worst	1	1.0	1.0	1.3

e. **Value Interpretation** - Value equals factor by which expected soil concentration exceeds background when sludge is applied. (A value of 2 indicates concentration is doubled; a value of 0.5 indicates reduction by one-half.)

f. **Preliminary Conclusion** - Soil concentrations of fluoride are not expected to change significantly due to landspreading of sludge. A high application of sludge containing a typical concentration of fluoride may decrease the soil concentration due to dilution, and a high application of sludge containing a high concentration of fluoride may increase the soil concentration by 30 percent.

B. Effect on Soil Biota and Predators of Soil Biota

1. Index of Soil Biota Toxicity (Index 2)

a. **Explanation** - Compares pollutant concentrations in sludge-amended soil with soil concentration shown to be toxic for some organism.

b. **Assumptions/Limitations** - Assumes pollutant form in sludge-amended soil is equally bioavailable and toxic as form used in study where toxic effects were demonstrated.

c. **Data Used and Rationale**

i. **Index of soil concentration increment (Index 1)**

See Section 3, p. 3-2.

ii. **Background concentration of pollutant in soil (BS)** = 292 µg/g DW

See Section 3, p. 3-2.

iii. **Soil concentration toxic to soil biota (TB)** - Data not immediately available.

d. **Index 2 Values** - Values were not calculated due to lack of data.

e. **Value Interpretation** - Value equals factor by which expected soil concentration exceeds toxic concentration. Value >1 indicates a toxic hazard may exist for soil biota.

f. **Preliminary Conclusion** - Conclusion was not drawn because index values could not be calculated.

2. Index of Soil Biota Predator Toxicity (Index 3)

a. **Explanation** - Compares pollutant concentrations expected in tissues of organisms inhabiting sludge-amended soil with food concentration shown to be toxic to a predator on soil organisms.

b. **Assumptions/Limitations** - Assumes pollutant form bioconcentrated by soil biota is equivalent in toxicity to form used to demonstrate toxic effects in predator. Effect level in predator may be estimated from that in a different species.

c. **Data Used and Rationale**

i. **Index of soil concentration increment (Index 1)**

See Section 3, p. 3-2.

ii. **Background concentration of pollutant in soil (BS)** = 292 µg/g DW

See Section 3, p. 3-2.

iii. **Uptake slope of pollutant in soil biota (UB)** - Data not immediately available.

iv. **Background concentration in soil biota (BB)** - Data not immediately available.

v. **Feed concentration toxic to predator (TR)** - Data not immediately available.

d. **Index 3 Values** - Values were not calculated due to lack of data.

e. **Value Interpretation** - Value equals factor by which expected concentration in soil biota exceeds that which is toxic to predator. Value > 1 indicates a toxic hazard may exist for predators of soil biota.

f. **Preliminary Conclusion** - Conclusion was not drawn because index values could not be calculated.

C. **Effect on Plants and Plant Tissue Concentration**

1. **Index of Phytotoxicity (Index 4)**

a. **Explanation** - Compares pollutant concentrations in sludge-amended soil with the lowest soil concentration shown to be toxic for some plant.

b. **Assumptions/Limitations** - Assumes pollutant form in sludge-amended soil is equally bioavailable and toxic as form used in study where toxic effects were demonstrated.

c. **Data Used and Rationale**

i. **Index of soil concentration increment (Index 1)**

See Section 3, p. 3-2.

ii. **Background concentration of pollutant in soil (BS)** = 292 µg/g DW

See Section 3, p. 3-2.

iii. **Soil concentration toxic to plants (TP) = 454 µg/g DW**

The soil concentration toxic to plants was chosen conservatively. This concentration represents the highest concentration tested by Davis (1980) in a study of rye grass uptake of fluoride following application of fluoride-rich sludge. No adverse effects were observed at this concentration, and, in fact, the yield was increased. Cooke et al. (1976, as cited by Davis, 1980) found no symptoms of toxicity in rye grass grown on fluorspar waste containing 17.42% fluoride. Although Cooke et al. (1976) reported a higher soil concentration where no effects were observed, the concentration of 454 µg/g was chosen as a conservative estimate (304 µg/g plus 150 µg/g background in experimental soil) of a concentration where effects might occur. A study by Morse (1935), cited in Eagers (1969), reported that a concentration of 100 µg/g greatly diminished seed germination of maize and 400 µg/g completely inhibited germination. However, these concentrations represent soluble fluoride rather than total fluoride, which would normally be less available to plants. Another study by Thompson et al. (1979) reported fluoride damage to fir trees where soil concentrations of fluoride were 36 µg/g. However, the soil fluoride concentrations in this study were the result of deposit of airborne fluoride from a factory. It was not clear to what degree the damage observed was due to atmospheric exposure to fluoride, since plants are known to accumulate fluoride and suffer injury from atmospheric exposure to fluoride (U.S. EPA, 1980). (See Section 4, p. 4-9.)

d. **Index 4 Values**

Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Typical	0.64	0.64	0.63	0.55
Worst	0.64	0.65	0.67	0.84

e. **Value Interpretation** - Value equals factor by which soil concentration exceeds phytotoxic concentration. Value > 1 indicates a phytotoxic hazard may exist.

f. **Preliminary Conclusion** - Fluoride in sludge-amended soil is not expected to pose a hazard to plants.

2. **Index of Plant Concentration Increment Caused by Uptake (Index 5)**

a. **Explanation** - Calculates expected tissue concentration increment in plants grown in sludge-amended soil, using uptake data for the most responsive plant species in the following categories: (1) plants included in the U.S. human diet; and (2) plants serving as animal feed. Plants used vary according to availability of data.

b. **Assumptions/Limitations** - Assumes a linear uptake slope. Neglects the effect of time; i.e., cumulative loading over several years is treated equivalently to single application of the same amount. The uptake factor chosen for the animal diet is assumed to be representative of all crops in the animal diet. See also Index 6 for consideration of phytotoxicity.

c. **Data Used and Rationale**

i. **Index of soil concentration increment (Index 1)**

See Section 3, p. 3-2.

ii. **Background concentration of pollutant in soil (BS) = 292 µg/g DW**

See Section 3, p. 3-2.

iii. **Conversion factor between soil concentration and application rate (CO) = 2 kg/ha $(\mu g/g)^{-1}$**

Assumes pollutant is distributed and retained within upper 15 cm of soil (i.e. plow layer) which has an approximate mass (dry matter) of 2×10^3.

iv. **Uptake slope of pollutant in plant tissue (UP)**

Animal diet:
Rye grass (tops)
0.0786 µg/g tissue DW $(kg/ha)^{-1}$

Human diet:
Ground cover (tops)
0.0098 µg/g tissue DW $(kg/ha)^{-1}$

Very limited data appropriate for calculation of uptake slopes are immediately available. Rye grass was chosen as the representative plant consumed by animals. The uptake slope of 0.0786 was calculated from data presented by Davis (1980) in a study which applied fluoride-

rich sludge at rates which equated to 0 to 672 kg/ha. An uptake slope for fescue was calculated to be 0.0059 µg/g tissue DW $(kg/ha)^{-1}$ based on data presented by Wright et al. (1978). However, to be conservative, the higher uptake slope for rye grass was chosen. No data were immediately available to estimate the uptake slope for plants consumed by humans. An uptake slope of 0.0098 was available for ground cover consisting largely of clover (Trifoliam repens). Wright et al. (1978) studied the uptake of fluoride in ground cover grown in soils contaminated with flouride. The value for ground cover appeared to be the most representative uptake slope available. It is assumed that uptake of fluoride by leafy vegetables is similar to the ground cover uptake. (See Section 4, p. 4-10.)

v. **Background concentration in plant tissue (BP)**

Animal diet:
Rye grass (tops) 6.0 µg/g DW

Human diet:
Ground cover (tops) 6.2 µg/g DW

Background concentrations of fluoride in rye grass and ground cover are those given by Davis (1980) and Wright et al. (1978), respectively, in the studies presenting data used to calculate the uptake slopes. (See Section 4, p. 4-10.)

d. **Index 5 Values**

Diet	Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Animal	Typical	1.0	0.99	0.87	-0.077
	Worst	1.0	1.0	1.3	3.3
Human	Typical	1.0	1.0	0.98	0.87
	Worst	1.0	1.0	1.0	1.3

e. **Value Interpretation** - Value equals factor by which plant tissue concentration is expected to increase above background when grown in sludge-amended soil.

f. **Preliminary Conclusion** - The concentrations of fluoride in plants consumed by animals and humans are not expected to increase as a result of

landspreading sludge, except when sludge with a high fluoride concentration is applied at high rates.

3. **Index of Plant Concentration Increment Permitted by Phytotoxicity (Index 6)**

   a. **Explanation** - Compares maximum plant tissue concentration associated with phytotoxicity with background concentration in same plant tissue. The purpose is to determine whether the plant concentration increments calculated in Index 5 for high applications are truly realistic, or whether such increases would be precluded by phytotoxicity.

   b. **Assumptions/Limitations** - Assumes that tissue concentration will be a consistent indicator of phytotoxicity.

   c. **Data Used and Rationale**

      i. **Maximum plant tissue concentration associated with phytotoxicity (PP)**

      Animal diet:
      Rye grass 2745 µg/g DW

      Human diet:
      Spinach 857 µg/g DW

      Available data indicate that rye grass is able to tolerate relatively high tissue concentrations without exhibiting phytotoxicity. A concentration of 2745 µg/g DW caused no signs of phytotoxicity in rye grass grown on fluorspar waste (Cooke et al., 1976 cited in Davis, 1980). In a pot study using fluoride-rich sludge, rye grass yield increased at the highest soil fluoride concentration; tissue fluoride was 60 µg/g DW (Davis, 1980). In spite of the fact that phytotoxicity was not observed, the data from Cooke et al. (1976) were chosen to conservatively maximize the value of Index 6. Spinach was chosen as a representative leafy vegetable consumed by humans for which tissue concentrations associated with toxicity were available. The spinach tissue concentrations associated with toxicity ranged from 803 to 857 µg/g DW (U.S. EPA, 1980). Therefore, the value of 857 µg/g DW represents the highest concentration associated with phytotoxicity. (See Section 4, p. 4-9.)

ii. **Background concentration in plant tissue (BP)**

Animal diet:
Rye grass 127 µg/g DW

Human diet:
Spinach 28.3 µg/g DW

The background tissue concentration for rye grass was obtained from Cooke et al. (1976) because the PP value for rye grass was taken from this study. Background concentrations for spinach were 35 µg/g DW reported by Benedict et al., 1964 (as cited in U.S. EPA, 1980) and 1.3 to 28.3 µg/g DW reported by Garber, 1967 (as cited in U.S. EPA, 1980). The value of 28.3 µg/g was chosen since it is between the highest and lowest values reported. (See Section 4, p. 4-6.)

d. **Index 6 Values**

Plant	Index Value
Rye grass	22
Spinach	30

e. **Value Interpretation** - Value gives the maximum factor of tissue concentration increment (above background) which is permitted by phytotoxicity. Value is compared with values for the same or similar plant tissues given by Index 5. The lowest of the two indices indicates the maximal increase which can occur at any given application rate.

f. **Preliminary Conclusion** - The maximum increase in fluoride concentration predicted for plants in the human and animal diet will not be precluded by phytotoxicity.

D. **Effect on Herbivorous Animals**

1. **Index of Animal Toxicity Resulting from Plant Consumption (Index 7)**

a. **Explanation** - Compares pollutant concentrations expected in plant tissues grown in sludge-amended soil with food concentration shown to be toxic to wild or domestic herbivorous animals. Does not consider direct contamination of forage by adhering sludge.

b. **Assumptions/Limitations** - Assumes pollutant form taken up by plants is equivalent in toxicity to form

used to demonstrate toxic effects in animal. Uptake or toxicity in specific plants or animals may be estimated from other species.

c. **Data Used and Rationale**

i. **Index of plant concentration increment caused by uptake (Index 5)**

Index 5 values used are those for an animal diet (see Section 3, p. 3-7).

ii. **Background concentration in plant tissue (BP) =** 6 µg/g DW

The background concentration value used is for the plant chosen for the animal diet (see Section 3, p. 3-7).

iii. **Feed concentration toxic to herbivorous animal (TA) =** 40 µg/g DW

The value for feed concentration represents the maximum dietary tolerance for dairy cattle and young cattle recommended by NAS (1980). The maximum dietary tolerance for mature beef cattle is 50 µg/g (NAS, 1980). Minor morphological lesions occur in the teeth of cattle when dietary fluoride exceeds 20 µg/g during tooth development; however, no relationship between these lesions and animal performance has been determined (NAS, 1980). Although Davis (1980) reported a toxic fluoride threshold of 30 µg/g for cattle, Baxter et al. (1983) reported no adverse effects for cattle at this feed concentration. (See Section 4, p. 4-11.)

d. **Index 7 Values**

Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Typical	0.15	0.15	0.13	-0.012
Worst	0.15	0.15	0.19	0.50

e. **Value Interpretation** - Value equals factor by which expected plant tissue concentration exceeds that which is toxic to animals. Value >1 indicates a toxic hazard may exist for herbivorous animals.

f. **Preliminary Conclusion** - Landspreading of sludge is not expected to pose a toxic hazard from fluoride to herbivorous animals that feed on plants grown on sludge-amended soil.

2. Index of Animal Toxicity Resulting from Sludge Ingestion (Index 8)

a. Explanation - Calculates the amount of pollutant in a grazing animal's diet resulting from sludge adhesion to forage or from incidental ingestion of sludge-amended soil and compares this with the dietary toxic threshold concentration for a grazing animal.

b. Assumptions/Limitations - Assumes that sludge is applied over and adheres to growing forage, or that sludge constitutes 5 percent of dry matter in the grazing animal's diet, and that pollutant form in sludge is equally bioavailable and toxic as form used to demonstrate toxic effects. Where no sludge is applied (i.e., 0 mt/ha), assumes diet is 5 percent soil as a basis for comparison.

c. Data Used and Rationale

i. Sludge concentration of pollutant (SC)

Typical	86.4 µg/g DW
Worst	738.7 µg/g DW

See Section 3, p. 3-1.

ii. Background concentration of pollutant in soil (BS) = 292 µg/g DW

See Section 3, p. 3-2.

iii. Fraction of animal diet assumed to be soil (GS) = 5%

Studies of sludge adhesion to growing forage following applications of liquid or filter-cake sludge show that when 3 to 6 mt/ha of sludge solids is applied, clipped forage initially consists of up to 30 percent sludge on a dry-weight basis (Chaney and Lloyd, 1979; Boswell, 1975). However, this contamination diminishes gradually with time and growth, and generally is not detected in the following year's growth. For example, where pastures amended at 16 and 32 mt/ha were grazed throughout a growing season (168 days), average sludge content of forage was only 2.14 and 4.75 percent, respectively (Bertrand et al., 1981). It seems reasonable to assume that animals may receive long-term dietary exposure to 5 percent sludge if maintained on a forage to which sludge is regularly applied. This estimate of 5 percent

sludge is used regardless of application rate, since the above studies did not show a clear relationship between application rate and initial contamination, and since adhesion is not cumulative yearly because of die-back.

Studies of grazing animals indicate that soil ingestion, ordinarily <10 percent of dry weight of diet, may reach as high as 20 percent for cattle and 30 percent for sheep during winter months when forage is reduced (Thornton and Abrams, 1983). If the soil were sludge-amended, it is conceivable that up to 5 percent sludge may be ingested in this manner as well. Therefore, this value accounts for either of these scenarios, whether forage is harvested or grazed in the field.

iv. **Feed concentration toxic to herbivorous animal (TA) = 40 µg/g DW**

See Section 3, p. 3-10.

d. **Index 8 Values**

Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Typical	0.37	0.11	0.11	0.11
Worst	0.37	0.92	0.92	0.92

e. **Value Interpretation** - Value equals factor by which expected dietary concentration exceeds toxic concentration. Value > 1 indicates a toxic hazard may exist for grazing animals.

f. **Preliminary Conclusion** - Landspreading of sludge is not expected to pose a toxic hazard from fluoride to grazing animals incidentally ingesting sludge-amended soil.

E. **Effect on Humans**

1. **Index of Human Toxicity Resulting from Plant Consumption (Index 9)**

a. **Explanation** - Calculates dietary intake expected to result from consumption of crops grown on sludge-amended soil. Compares dietary intake with acceptable daily intake (ADI) of the pollutant.

b. **Assumptions/Limitations** - Assumes that all crops are grown on sludge-amended soil and that all those

considered to be affected take up the pollutant at the same rate as the most responsive plant(s) (as chosen in Index 5). Divides possible variations in dietary intake into two categories: toddlers (18 months to 3 years) and individuals over 3 years old.

c. Data Used and Rationale

i. Index of plant concentration increment caused by uptake (Index 5)

Index 5 values used are those for a human diet (see Section 3, p. 3-7).

ii. Background concentration in plant tissue (BP) = 28.3 µg/g DW

The background concentration value used is for spinach, which was chosen as the plant for the human diet in Index 6 (see Section 3, p. 3-9). This value was chosen, rather than the background concentration for ground cover, since it is higher, and thus, a more conservative choice and since it represents a plant actually consumed by humans.

iii. Daily human dietary intake of affected plant tissue (DT)

Toddler	74.5 g/day
Adult	205 g/day

The intake value for adults is based on daily intake of crop foods (excluding fruit) by vegetarians (Ryan et al., 1982); vegetarians were chosen to represent the worst case. The value for toddlers is based on the FDA Revised Total Diet (Pennington, 1983) and food groupings listed by the U.S. EPA (1984). Dry weights for individual food groups were estimated from composition data given by the U.S. Department of Agriculture (USDA) (1975). These values were composited to estimated dry-weight consumption of all non-fruit crops.

iv. Average daily human dietary intake of pollutant (DI)

Toddler	825 µg/day
Adult	2500 µg/day

The estimated daily intake of fluoride for toddlers, age 1 to 3, was reported to range from 417 to 825 µg/day when intake from food and

water are totalled (U.S. EPA 1980, adapted from Maier, 1971). The higher value, 825 µg/day was selected to represent the average daily intake. U.S. EPA (1980) also reported that daily fluoride intake from food for 1- to 2-year old children was 250 to 550 µg/day (adapted from Jones, Harries, and Martin, 1971); however, this value did not include intake from drinking water. The dietary intake in the U.S. for adults from food and fluoridated drinking water is 2500 µg/day (U.S. EPA, 1980 adapted from Jones, Harries, and Martin, 1971). This value is considered a conservative choice since fluoridated drinking water is included in the value. Other values reported are 1800 µg/day for men and 1300 µg/day for housewives (Cholak, 1960, in U.S. EPA, 1980), and 2100 to 2400 µg/day for young adult U.S. males (San Filippo and Battistone, 1971, in U.S. EPA, 1980).

v. **Acceptable daily intake of pollutant (ADI) = 4000 µg/day**

Singh and Jolly (1970, in U.S. EPA, 1980) considered that 4000 to 5000 µg is the daily limit that may be ingested without hazardous body storage. Areas of endemic fluorosis commonly have levels of ingestion of over 8000 µg/day. Since no ADIs for fluoride have been recommended, the value of 4000 was chosen to represent the ADI.

d. Index 9 Values

Group	Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Toddler	Typical	0.21	0.21	0.20	0.14
	Worst	0.21	0.21	0.22	0.36
Adult	Typical	0.62	0.62	0.60	0.44
	Worst	0.62	0.63	0.67	1.0

e. Value Interpretation - Value equals factor by which expected intake exceeds ADI. Value > 1 indicates a possible human health threat. Comparison with the null index value at 0 mt/ha indicates the degree to which any hazard is due to sludge application, as opposed to pre-existing dietary sources.

f. **Preliminary Conclusion** - Landspreading of sludge is not expected to pose a health hazard from fluoride to humans who consume crops grown on sludge-amended soil.

2. **Index of Human Toxicity Resulting from Consumption of Animal Products Derived from Animals Feeding on Plants (Index 10)**

a. **Explanation** - Calculates human dietary intake expected to result from consumption of animal products derived from domestic animals given feed grown on sludge-amended soil (crop or pasture land) but not directly contaminated by adhering sludge. Compares expected intake with ADI.

b. **Assumptions/Limitations** - Assumes that all animal products are from animals receiving all their feed from sludge-amended soil. The uptake slope of pollutant in animal tissue (UA) used is assumed to be representative of all animal tissue comprised by the daily human dietary intake (DA) used. Divides possible variations in dietary intake into two categories: toddlers (18 months to 3 years) and individuals over 3 years old.

c. **Data Used and Rationale**

i. **Index of plant concentration increment caused by uptake (Index 5)**

Index 5 values used are those for an animal diet (see Section 3, p. 3-7).

ii. **Background concentration in plant tissue (BP) = 6 µg/g DW**

The background concentration value used is for the plant chosen for the animal diet (see Section 3, p. 3-7).

iii. **Uptake slope of pollutant in animal tissue (UA) = 0.03176 µg/g tissue DW (µg/g feed DW)$^{-1}$**

The uptake slope for animal tissue was calculated from data for beef liver presented by Suttie et al. (1958, in U.S. EPA, 1980). Beef liver was chosen as the representative tissue of grazing animals that is consumed by humans and for which an uptake slope could be calculated. Uptake slopes were available for beef heart and kidney (0.04365 and 0.31838, respectively); however, these tissues generally do not constitute a substantial fraction of the

human diet. Uptake slopes were also calculated for various turkey tissues, based on data presented by Anderson et al. (1955, in U.S. EPA, 1980). With the exception of bone, the uptake slopes were lower than those for beef liver. Also, turkeys are less representative of grazing animals than cattle.

iv. **Daily human dietary intake of affected animal tissue (DA)**

Toddler 0.97 g/day
Adult 5.76 g/day

The FDA Revised Total Diet (Pennington, 1983) lists average daily intake of beef liver fresh weight for various age-sex classes. The 95th percentile of liver consumption (chosen in order to be conservative) is assumed to be approximately 3 times the mean values. Conversion to dry weight is based on data from U.S. Department of Agriculture (1975).

v. **Average daily human dietary intake of pollutant (DI)**

Toddler 825 µg/day
Adult 2500 µg/day

See Section 3, p. 3-13.

vi. **Acceptable daily intake of pollutant (ADI) = 4000 µg/day**

See Section 3, p. 3-14.

d. **Index 10 Values**

Group	Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Toddler	Typical	0.21	0.21	0.21	0.21
	Worst	0.21	0.21	0.21	0.21
Adult	Typical	0.62	0.62	0.62	0.62
	Worst	0.62	0.62	0.62	0.62

e. **Value Interpretation** - Same as for Index 9.

f. **Preliminary Conclusion** - Landspreading of sludge is not expected to pose a health hazard from fluoride to humans who consume animal products derived from livestock fed crops grown on sludge-amended soil.

3. **Index of Human Toxicity Resulting from Consumption of Animal Products Derived from Animals Ingesting Soil (Index 11)**

a. **Explanation** - Calculates human dietary intake expected to result from consumption of animal products derived from grazing animals incidentally ingesting sludge-amended soil. Compares expected intake with ADI.

b. **Assumptions/Limitations** - Assumes that all animal products are from animals grazing sludge-amended soil, and that all animal products consumed take up the pollutant at the highest rate observed for muscle of any commonly consumed species or at the rate observed for beef liver or dairy products (whichever is higher). Divides possible variations in dietary intake into two categories: toddlers (18 months to 3 years) and individuals over three years old.

c. **Data Used and Rationale**

i. **Animal tissue = Beef liver**

See Section 3, p. 3-15.

ii. **Background concentration of pollutant in soil (BS) = 292 µg/g DW**

See Section 3, p. 3-2.

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

Typical	86.4 µg/g DW
Worst	738.7 µg/g DW

See Section 3, p. 3-1.

iv. **Fraction of animal diet assumed to be soil (GS) = 5%**

See Section 3, p. 3-11.

v. **Uptake slope of pollutant in animal tissue (UA) = 0.03176 µg/g tissue DW (µg/g feed DW)$^{-1}$**

See Section 3, p. 3-15.

vi. **Daily human dietary intake of affected animal tissue (DA)**

Toddler 0.97 g/day
Adult 5.76 g/day

See Section 3, p. 3-16.

vii. **Average daily human dietary intake of pollutant (DI)**

Toddler 825 µg/day
Adult 2500 µg/day

See Section 3, p. 3-13.

viii. **Acceptable daily intake of pollutant (ADI)** = 4000 µg/day

See Section 3, p. 3-14.

d. **Index 11 Values**

Group	Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Toddler	Typical	0.21	0.21	0.21	0.21
	Worst	0.21	0.21	0.21	0.21
Adult	Typical	0.63	0.63	0.63	0.63
	Worst	0.63	0.63	0.63	0.63

e. **Value Interpretation** - Same as for Index 9.

f. **Preliminary Conclusion** - Landspreading of sludge is not expected to pose a health hazard from fluoride to humans who consume animal products derived from livestock which had incidentally ingested sludge-amended soil.

4. **Index of Human Toxicity from Soil Ingestion (Index 12)**

a. **Explanation** - Calculates the amount of pollutant in the diet of a child who ingests soil (pica child) amended with sludge. Compares this amount with ADI.

b. **Assumptions/Limitations** - Assumes that the pica child consumes an average of 5 g/day of sludge-amended soil. If an ADI specific for a child is not available, this index assumes that the ADI for a 10 kg child is the same as that for a 70 kg adult. It is thus assumed that uncertainty factors used in

deriving the ADI provide protection for the child, taking into account the smaller body size and any other differences in sensitivity.

c. **Data Used and Rationale**

i. **Index of soil concentration increment (Index 1)**

See Section 3, p. 3-2.

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

Typical	86.4 µg/g DW
Worst	738.7 µg/g DW

See Section 3, p. 3-1.

iii. **Background concentration of pollutant in soil (BS) = 292 µg/g DW**

See Section 3, p. 3-2.

iv. **Assumed amount of soil in human diet (DS)**

Pica child	5 g/day
Adult	0.02 g/day

The value of 5 g/day for a pica child is a worst-case estimate employed by U.S. EPA's Exposure Assessment Group (U.S. EPA, 1983). The value of 0.02 g/day for an adult is an estimate from U.S. EPA (1984).

v. **Average daily human dietary intake of pollutant (DI)**

Toddler	825 µg/day
Adult	2500 µg/day

See Section 3, p. 3-13.

vi. **Acceptable daily intake of pollutant (ADI) = 4000 µg/day**

See Section 3, p. 3-14.

d. **Index 12 Values**

Group	Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500	Pure Sludge
Toddler	Typical	0.57	0.57	0.56	0.52	0.31
	Worst	0.57	0.57	0.58	0.68	1.1
Adult	Typical	0.63	0.63	0.63	0.63	0.63
	Worst	0.63	0.63	0.63	0.63	0.63

e. **Value Interpretation** - Same as for Index 9.

f. **Preliminary Conclusion** - Ingestion of sludge-amended soil is not expected to pose a human health hazard due to fluoride, except possibly for toddlers who ingest pure sludge containing a high concentration of fluoride.

5. **Index of Aggregate Human Toxicity (Index 13)**

a. **Explanation** - Calculates the aggregate amount of pollutant in the human diet resulting from pathways described in Indices 9 to 12. Compares this amount with ADI.

b. **Assumptions/Limitations** - As described for Indices 9 to 12.

c. **Data Used and Rationale** - As described for Indices 9 to 12.

d. **Index 13 Values**

Group	Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Toddler	Typical	0.57	0.57	0.56	0.45
	Worst	0.57	0.57	0.60	0.83
Adult	Typical	0.63	0.62	0.60	0.44
	Worst	0.63	0.63	0.68	1.0

e. **Value Interpretation** - Same as for Index 9.

f. **Preliminary Conclusion** - An aggregate human health hazard due to fluoride is not expected to occur as a result of landspreading sludge.

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

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.

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 FLUORIDE IN MUNICIPAL SEWAGE SLUDGE

I. OCCURRENCE

A. Sludge

1. Frequency of Detection

Assumed 100% because of its use as an additive in water, toothpaste, etc., and because of its ubiquitous nature.

2. Concentration

Sludges of 16 U.S. cities		Furr et al., 1976 (p. 684)
Median	= 86.4 µg/g DW	Derived from sludge concentration data presented in U.S. EPA, 1982
Mean	= 167.3 µg/g DW	
95th percentile	= 738.7 µg/g DW	
Minimum	= 2.2 µg/g DW	
33,500 ppm in fluoride-contaminated sludge		Davis, 1980 (p. 279)

B. Soil - Unpolluted

1. Frequency of Detection

13th element in abundance constituting 0.06 to 0.09% of earth's crust	U.S. EPA, 1980 (p. 1)

2. Concentration

209±23 ppm (DW) in controlled soil (Great Britain)	Wright et al., 1978 (p. 305)
20 to 500 ppm in soils 0 to 3 in. in depth, mean 190 ppm	Robinson and Edgington, 1946 in NAS, 1971 (p. 6)

20 to 1620 ppm in soils 0 to 12 in. in depth, mean 292 ppm (30 soils sampled throughout the United States)	Robinson and Edgington, 1946 in NAS, 1971 (p. 6)
Max levels: Idaho Soil - 3870 ppm	Robinson and Edgington, 1946 in NAS 1971 (p. 6)
Tenn. Soil - 8300 ppm	McIntire, 1949 in NAS, 1971 (p. 6)
200 to 300 ppm "normal" for mineral soils	U.S. EPA, 1980 (p. 2)
200 ppm common value	Bowen, 1966 in Davis, 1980

C. Water - Unpolluted

1. Frequency of Detection

Assumed 100%

2. Concentration

a. Freshwater

<0.3 ppm	U.S. EPA, 1980 (p. 9)

b. Seawater

1.4 to 1.5 ppm	U.S. EPA, 1980 (p. 9)
1.3 mg/L	Hem, 1970 (p. 11)

c. Drinking water

0.02 to 0.1 ppm in northwest United States; >0.2 ppm in west, midwest and south U.S. water supplies	NAS, 1971 (p. 6)

D. Air

1. Frequency of Detection

Only 3% of samples from rural locations had detectable fluoride	NAS, 1971 (p. 233)

2. **Concentration**

a. **Urban**

<0.05 μg/m^3	U.S. EPA, 1980 (p. 2)
>3 μg/m^3 in industrial areas	(p. 3)
87% of samples <0.05 μg/m^3	NAS, 1971 (p. 233)

b. **Rural**

<0.05 μg/m^3	U.S. EPA, 1980 (p. 2)
0.16 μg/m^3 highest concentration	NAS, 1971 (p. 43)

E. **Food**

1. **Total Average Intake**

417 to 825 μg/day - intake from food and drinking water for children age 1-3 years	U.S. EPA, 1980 adapted from Maier, 1971 (p. 397)
250 to 550 μg/day - intake from food for children, age 1-2 years in the U.S.	U.S. EPA, 1980 adapted from Jones et al., 1971 (p. 399)
2500 μg/day - dietary intake from food and fluoridated drinking water in the U.S.	U.S. EPA, 1980 adapted from Jones et al., 1971 (p. 399)
1800 μg/day - intake for men 1300 μg/day - intake for housewives	Cholak, 1960 in U.S. EPA, 1980 (p. 397)
2100 to 2400 μg/day - daily intake for young adult U.S. males	San Filippo and Battistone, 1971 in U.S. EPA, 1980 (p. 397)
0.2 to 0.3 mg/day in average adult diet 1.0 mg/day or greater in drinking water	NAS, 1971 (p. 7)

2. **Concentration**

Typical Concentrations in Fresh Food		Cholak, 1959, in NAS, 1971 (p. 8)
Meats	0.01 - 7.70 ppm	
Fish	<0.10 - 24.00 ppm	
Citrus fruits	0.04 - 0.36 ppm	
Noncitrus fruits	0.02 - 1.32 ppm	
Vegetables	0.10 - 3.00 ppm	
Cereals and cereal products	<0.10 - 20.00 ppm	
Milk	0.04 - 0.55 ppm	
Eggs	0.00 - 2.05 ppm	
Butter	0.40 - 1.50 ppm	
Cheese	0.13 - 1.62 ppm	
Sugar	0.10 - 0.32 ppm	
Coffee	0.20 - 1.60 ppm	
Beer	0.15 - 0.86 ppm	
Wine	0.00 - 6.34 ppm	

II. HUMAN EFFECTS

A. Ingestion

1. Carcinogenicity

a. Qualitative Assessment

No evidence of carcinogenicity induced by ingestion of fluorides — U.S. EPA, 1980 (p. 320)

2. Chronic Toxicity

a. ADI

4000 to 5000 µg/day - daily limit that may be ingested without hazardous body storage — Singh and Jolly, 1970 in U.S. EPA, 1980 (p. 292)

b. Effects

No effects observed at drinking water levels of 0.8 mg/L
Teeth mottled in children at drinking water levels of 1.0 to 6.0 mg/L
Sublethal level in drinking water at 115 mg/L
Toxic to man in drinking water at 180 mg/L
Lethal dose in drinking water of 2000 mg/L — California State Water Resources Control Board, 1978 (p. 190)

3. **Absorption Factor**

1 to 10 percent

4. **Existing Regulations**

Ambient Water Quality Criteria ≤1.0 mg/L	California State Water Resources Control Board, 1978 (p. 190)

B. Inhalation

1. **Carcinogenicity**

a. **Qualitative Assessment**

Not found to be carcinogenic to humans when inhaled.

2. **Chronic Toxicity**

a. **Inhalation Threshold or MPIH**

See below, "Existing Regulations"

b. **Effects**

Overexposure (short term): Irritation of eyes and respiratory tract.	U.S. Dept. of Labor, 1978
Overexposure (long-term): Calcification of bones and ligaments, mottled teeth, or skin rash.	

3. **Absorption Factor.**

Data not immediately available.

4. **Existing Regulations**

2.5 mg/m^3 (TWA)	ACGIH, 1982

III. PLANT EFFECTS

A. Phytotoxicity

Most plants absorb very little fluoride from the soil	NAS, 1971 (p. 7)

See Table 4-1.

No cases of fluorosis have ever been ascribed to excessive "natural" accumulation of fluorides in plant tissues — Baxter et al., 1983

Threshold for injury for susceptible plants is <150 ppm in tissues
Intermediate plants threshold is >200 ppm — NAS, 1971 (p. 98)

B. Uptake

"Normal" concentrations: Festuca rubra 5.01±1.1 ppm DW
Composite ground cover 8.1+1.3 ppm DW — Wright et al., 1978 (p. 305)

"Natural" forage fluoride 5-10 ppm DW
Uncontaminated alfalfa (107 samples) 0.8-36.5 ppm (DW), 3.6, median 2 ppm — NAS, 1971 (p. 136)

Crops uncontaminated by aerial deposition of fluorides contain 2 to 20 ppm fluoride — Baxter et al., 1983 (p. 14)

2 to 20 µg/g (DW) — U.S. EPA, 1980 (p. 5)

Fluoride Concentration in Selected Plants — U.S. EPA, 1980 (p. 119-120)

Plant	Part	Fluoride (ppm DW)	
Alfalfa	Tops	7-15	Zimmerman and Hitchcock, 1956
Grass, Hay	Plant	1-6	Garber, 1967
Corn	Cob	1.6	Garber, 1967
Wheat	Grain	1	Garber, 1967
Rye	Grain	1.5	Garber, 1967
Oats	Grain	0.5	Garber, 1967
Rice	Grain	0.76	Garber, 1967
Potato	Tuber	1.5-3.0	Garber, 1967
Lettuce	Leaf	4.4-11.3	Garber, 1967
Spinach	Leaf	1.3-28.3	Garber, 1967
Spinach	Leaf	35	Benedict et al, 1964
Celery	Stalk	2	Zimmerman and Hitchcock, 1956
Carrot	Root	0.4-8.4	Garber, 1967
Tomato	Fruit	2	Zimmerman and Hitchcock, 1956

<30 ppm in 90% of 168 samples of dairy feed, "some samples had over 200 ppm"	Suttie et al., 1958 in U.S. EPA, 1980 (p. 137)
"There is little or no relation between total fluoride content of soil and the fluoride content of plants grown on it. There is some indication that acid soil promotes fluoride uptake..."	NAS, 1971 (p. 136)
"Because soil fluoride may be unavailable to plants, a direct relationship between soil fluoride content and plant fluoride content does not necessarily exist."	U.S. EPA, 1980

See Table 4-2.

IV. DOMESTIC ANIMAL AND WILDLIFE EFFECTS

A. Toxicity

See Table 4-3.

B. Uptake

See Table 4-4.

V. AQUATIC LIFE EFFECTS

Data not immediately available.

VI. SOIL BIOTA EFFECTS

Only data available are fluoride pesticides

VII. PHYSICOCHEMICAL DATA FOR ESTIMATING FATE AND TRANSPORT

Low soil pH greatly increases fluoride solubility and, therefore, availability of fluoride to plants	Doss et al., 1977 (p. 367)
Fluorides are mostly insoluble and, therefore, not particularly available to plants	Baxter, et al., 1983 (p. 14)
CaF_2 (fluorite) Molecular wt.: 78.08 Solubility in water (18°C): 0.0016 g/100 mL	Hodgman et al., 1961
MgF_2 (sellaite) Molecular wt.: 62.32 Solubility in water (18°C): 0.0076 g/100 mL	Hodgman et al., 1961

NaF (villiaumite)
Molecular wt.: 42.00
Solubility in water (18°C): 4.22 g/100 mL

Hodgman et al. 1961

TABLE 4-1. PHYTOTOXICITY OF FLUORIDE

Plant/Tissue	Chemical Form Applied	Growth Medium	Control Tissue Concentration (µg/g DW)	Experimental Soil Concentration (µg/g DW)	Experimental Application Rate (kg/ha)	Experimental Tissue Concentration (µg/g DW)	Effect	References
Rye grass	F-rich liquid-digested sludge (pot study)	soil pH 7.0	6	188	84	NR	Increased yield	Davis, 1980
				246	168	NR	Increased yield	
				302	336	NR	Increased yield	
				454	672	60	Increased yield	
Perennial rye grass (Lolium perenne)	Fluorspar waste	NR	174	200	NR	2745	No symptoms of toxicity	Cooke et al., 1976 in Davis 1980 (p. 181)
Maize	Soluble F	NR[a]	NR	100		NR	Greatly diminishes germination	Morse, 1935 in Eagers, 1969
				400		NR	Completely inhibits germination	Morse, 1935 in Eagers, 1969
Fir Tree	Airborne F	NR	7	10		7	No damage	Thompson et al., 1979
				16		44	Slight damage[b]	
				36		91	20-30% trees dead[b]	
				205		141	40-60% trees dead[b]	
				908		281	80-95% trees dead[b]	
Apple/leaf	HF gas	NA[c]	NA	NA	NA	72-234	Toxic symptoms	U.S. EPA, 1980
Apricot/leaf	HF gas or industrial emission	NA	NA	NA	NA	58-640	Toxic symptoms	
Bean/leaf	NaF	NR	NR	NR	NR	<310	Toxic symptoms	
Carrot/leaf	HF gas	NR	NR	NA	NA	250-723	Toxic symptoms	
Corn/leaf	HF gas	NR	NR	NA	NA	48-491	Toxic symptoms	
Spinach/leaf	NaF	NR		NR	NR	803-857	Toxic symptoms	
Tomato/leaf	NaF	NR	NR	NR	NR	277-2179	Toxic symptoms	
Citrus/leaves	NR	NR	NR	NR	NR	100-200	Significant yield and growth reduction	NAS, 1971

[a] NR = Not reported.
[b] Results of study unclear as to whether toxicity was due to atmospheric F damage or soil concentration.
[c] NA = Not available.

TABLE 4-2. UPTAKE OF FLUORIDE BY PLANTS

Plant/Tissue	Application Medium (Study Type)	Soil pH	Range (N)[a] of Application Rates (kg/ha)[a]	Control Tissue Concentration (µg/g DW)	Uptake Slope[b]	References
Rye grass/ tops	F-rich liquid-digested sludge (pot study)	7.0	0-672 (5)	6	0.0786	Davis, 1980
Ground covered/ tops[d]	contaminated soil	NR	0-348,000 (4)[c]	6.2	0.0098	Wright et al., 1978
Fescue/tops	contaminated soil	NR	0-348,000 (4)[c]	4.7	0.0059	Wright et al., 1978

[a]N = number of application rates, including control.
[b]Slope = y/x: x = kg applied/ha; y = µg/g plant tissue dry weight.
[c]Concentrations reported in Wright (1978) converted by kg/ha by subtracting background concentration and then calculating mass F in ha 15 cm deep.
[d]High frequency of Trifolium repens (clover).

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

Species	Chemical Form Fed	Feed Concentration (µg/g)	Water Concentration (mg/L)	Daily Intake (mg/kg)	Duration of Study	Effects	References
Sheep	NR	60	NR	NR	NR	Safe level	U.S. EPA, 1980
Horses	NR	30	NR	NR	NR	Safe level	
Cattle	NR	30	NR	NR	NR	Toxic threshold	Davis, 1980
Cattle	NR	30	NR	NR	NR	No adverse effects	Baxter et al., 1983
Cattle, horses, sheep	Sludge	<100	NR	NR	NR	Presents little hazard to grazing animals	
Cattle, swine, sheep, horse	NR	300	NR	NR	NR	No acute signs of toxicosis observed	U.S. EPA, 1980
Mature dairy cattle and young cattle	NaF	40	NR	NR	NR	Maximum dietary tolerance	NAS, 1980
Mature beef	NaF	50	NR	NR	NR	Maximum dietary tolerance	
Young cattle	NaF	20	NR	NR	NR	Minor morphological lesions in teeth; however no relationship between teeth and animal performance established	NAS, 1980
Feeder lambs	NaF	150	NR	NR	NR	Maximum dietary tolerance	
Horses	NaF	40	NR	NR	NR	Maximum dietary tolerance	
Pigs	NaF	150	NR	NR	NR	Maximum dietary tolerance	
Chickens	NaF	200	NR	NR	NR	Maximum dietary tolerance	

TABLE 4-3. (Continued)

Species	Chemical Form Fed	Feed Concentration (µg/g)	Water Concentration (mg/L)	Daily Intake (mg/kg)	Duration of Study	Effects	References
Turkeys	NR	150	NR	NR	NR	Maximum dietary tolerance	
Cattle	NR	>600	NR	NR	NR	Highly toxic	Hobbs et al., 1954 in NAS, 1971
Sheep	NaF	40	NR	NR	2 days	Inappetence	Ammerman et al., 1980
Sheep	CaF_2	2400	NR	NR	NR	No inappetence	Ammerman et al., 1980

[a] NR = Not reported.

TABLE 4-4. UPTAKE OF FLUORIDE BY DOMESTIC ANIMALS AND WILDLIFE

Species (N)[a]	Chemical Form Fed	Range (Number)[a] of Feed Concentrations[b] (µg/g DW)	Tissue Analyzed	Control Tissue Concentration (µg/g DW)[c]	Uptake Slope[b,c]	References
Field mole (5)	CaF_2	6.6-4215(3)	femur	117	0.4771	Wright et al., 1978
			kidney	6.7	0.0163	
			liver	5.4	0.00596	
			muscle	4.2	0.00041	
Voles Apodemus (14) Sorex (3)	CaF_2	6.6-4215(3)	femur	189	0.9238	Wright et al., 1978
Turkey	NaF	0-1600(7)	femur	NS[d]	7.7648	Anderson et al., 1955 in U.S. EPA, 1980
			breast flesh	1.2	0.0173	
			thigh flesh	1.5	0.0065	
			liver	1.9	0.0085	
			kidney	2.6	0.0203	
Cattle	NR[e]	0-50(5)	heart	2.3	0.04365	Suttie et al., 1958 in U.S. EPA, 1980
			liver	2.3	0.03176	
			kidney	3.5	0.31838	

[a]N = Number of animals/treatment group.
[b]When tissue values were reported as wet weight, unless otherwise indicated a moisture content of 77% was assumed for kidney, 70% for liver and 12% for muscle.
[c]Slope = y/x; y = µg/g feed; x = µg/g tissue.
[d]NS = Tissue concentration not significantly increased.
[e]NR = Not reported.

SECTION 5

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APPENDIX

PRELIMINARY HAZARD INDEX CALCULATIONS FOR FLUORIDE IN MUNICIPAL SEWAGE SLUDGE

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

A. Effect on Soil Concentration of Fluoride

1. Index of Soil Concentration Increment (Index 1)

a. Formula

$$\text{Index 1} = \frac{(SC \times AR) + (BS \times MS)}{BS\ (AR + MS)}$$

where:

SC = Sludge concentration of pollutant (µg/g DW)
AR = Sludge application rate (mt DW/ha)
BS = Background concentration of pollutant in soil (µg/g DW)
MS = 2000 mt DW/ha = Assumed mass of soil in upper 15 cm

b. Sample calculation

$$0.998 = \frac{(86.4\ \mu g/g\ DW \times 5\ mt/ha) + (292\ \mu g/g\ DW \times 2000\ mt/ha)}{292\ \mu g/g\ DW\ (5\ mt/ha + 2000\ mt/ha)}$$

B. Effect on Soil Biota and Predators of Soil Biota

1. Index of Soil Biota Toxicity (Index 2)

a. Formula

$$\text{Index 2} = \frac{I_1 \times BS}{TB}$$

where:

I_1 = Index 1 = Index of soil concentration increment (unitless)
BS = Background concentration of pollutant in soil (µg/g DW)
TB = Soil concentration toxic to soil biota (µg/g DW)

b. **Sample calculation** - Values were not calculated due to lack of data.

2. **Index of Soil Biota Predator Toxicity (Index 3)**

a. **Formula**

$$\text{Index 3} = \frac{(I_1 - 1)(BS \times UB) + BB}{TR}$$

where:

I_1 = Index 1 = Index of soil concentration increment (unitless)
BS = Background concentration of pollutant in soil (µg/g DW)
UB = Uptake slope of pollutant in soil biota (µg/g tissue DW [µg/g soil DW]$^{-1}$)
BB = Background concentration in soil biota (µg/g DW)
TR = Feed concentration toxic to predator (µg/g DW)

b. **Sample calculation** - Values were not calculated due to lack of data.

C. **Effect on Plants and Plant Tissue Concentration**

1. **Index of Phytotoxicity (Index 4)**

a. **Formula**

$$\text{Index 4} = \frac{I_1 \times BS}{TP}$$

where:

I_1 = Index 1 = Index of soil concentration increment (unitless)
BS = Background concentration of pollutant in soil (µg/g DW)
TP = Soil concentration toxic to plants (µg/g DW)

b. **Sample calculation**

$$0.642 = \frac{0.998 \times 292 \text{ µg/g DW}}{454 \text{ µg/g DW}}$$

2. **Index of Plant Concentration Increment Caused by Uptake (Index 5)**

   a. **Formula**

$$\text{Index 5} = \frac{(I_1 - 1) \times BS}{BP} \times CO \times UP + 1$$

   where:

   I_1 = Index 1 = Index of soil concentration increment (unitless)
   BS = Background concentration of pollutant in soil (µg/g DW)
   CO = 2 kg/ha $(\mu g/g)^{-1}$ = Conversion factor between soil concentration and application rate
   UP = Uptake slope of pollutant in plant tissue (µg/g tissue DW $[kg/ha]^{-1}$)
   BP = Background concentration in plant tissue (µg/g DW)

   b. **Sample calculation**

$$0.987 = \frac{(0.998-1) \times 292\ \mu g/g\ DW}{6\ \mu g/g\ DW} \times \frac{2\ kg/ha}{\mu g/g\ soil}$$

$$\times \frac{0.0786\ \mu g/g\ tissue}{kg/ha} + 1$$

3. **Index of Plant Concentration Increment Permitted by Phytotoxicity (Index 6)**

   a. **Formula**

$$\text{Index 6} = \frac{PP}{BP}$$

   where:

   PP = Maximum plant tissue concentration associated with phytotoxicity (µg/g DW)
   BP = Background concentration in plant tissue (µg/g DW)

   b. **Sample calculation**

$$21.6 = \frac{2745\ \mu g/g\ DW}{127\ \mu g/g\ DW}$$

C. Effect on Herbivorous Animals

1. Index of Animal Toxicity Resulting from Plant Consumption (Index 7)

a. Formula

$$\text{Index 7} = \frac{I_5 \times BP}{TA}$$

where:

I_5 = Index 5 = Index of plant concentration increment caused by uptake (unitless)
BP = Background concentration in plant tissue (µg/g DW)
TA = Feed concentration toxic to herbivorous animal (µg/g DW)

b. Sample calculation

$$0.148 = \frac{0.987 \times 6 \text{ µg/g DW}}{40 \text{ µg/g DW}}$$

2. Index of Animal Toxicity Resulting from Sludge Ingestion (Index 8)

a. Formula

$$\text{If AR} = 0, \quad I_8 = \frac{BS \times GS}{TA}$$

$$\text{If AR} \neq 0, \quad I_8 = \frac{SC \times GS}{TA}$$

where:

AR = Sludge application rate (mt DW/ha)
SC = Sludge concentration of pollutant (µg/g DW)
BS = Background concentration of pollutant in soil (µg/g DW)
GS = Fraction of animal diet assumed to be soil (unitless)
TA = Feed concentration toxic to herbivorous animal (µg/g DW)

b. Sample calculation

$$\text{If AR} = 0, \quad 0.365 = \frac{292 \text{ µg/g DW} \times 0.05}{40 \text{ µg/g DW}}$$

$$\text{If AR} \neq 0, \quad 0.108 = \frac{86.4 \text{ µg/g DW} \times 0.05}{40 \text{ µg/g DW}}$$

E. Effect on Humans

1. Index of Human Toxicity Resulting from Plant Consumption (Index 9)

a. Formula

$$\text{Index 9} = \frac{[(I_5 - 1)\ BP \times DT] + DI}{ADI}$$

where:

I_5 = Index 5 = Index of plant concentration increment caused by uptake (unitless)
BP = Background concentration in plant tissue (µg/g DW)
DT = Daily human dietary intake of affected plant tissue (g/day DW)
DI = Average daily human dietary intake of pollutant (µg/day)
ADI = Acceptable daily intake of pollutant (µg/day)

b. Sample calculation (toddler)

$$0.205 = \frac{[(0.987 - 1) \times 28.3\ \mu g/g\ DW \times 74.5\ g/day] + 825\ \mu g/day}{4000\ \mu g/day}$$

2. Index of Human Toxicity Resulting from Consumption of Animal Products Derived from Animals Feeding on Plants. (Index 10)

a. Formula

$$\text{Index 10} = \frac{[(I_5 - 1)\ BP \times UA \times DA] + DI}{ADI}$$

where:

I_5 = Index 5 = Index of plant concentration increment caused by uptake (unitless)
BP = Background concentration in plant tissue (µg/g DW)
UA = Uptake slope of pollutant in animal tissue (µg/g tissue DW [µg/g feed DW]$^{-1}$)
DA = Daily human dietary intake of affected animal tissue (g/day DW)
DI = Average daily human dietary intake of pollutant (µg/day)
ADI = Acceptable daily intake of pollutant (µg/day)

b. Sample calculation (toddler)

$$06 = \frac{[(0.987-1) \times 6\ \mu g/g\ DW \times 0.03176\ \mu g/g\ tissue[\mu g/g\ feed]^{-1} \times 0.97\ g/day] + 825\ \mu g/day}{4000\ \mu g/day}$$

3. Index of Human Toxicity Resulting from Consumption of Animal Products Derived from Animals Ingesting Soil (Index 11)

a. Formula

$$\text{If AR} = 0, \quad \text{Index 11} = \frac{(BS \times GS \times UA \times DA) + DI}{ADI}$$

$$\text{If AR} \neq 0, \quad \text{Index 11} = \frac{(SC \times GS \times UA \times DA) + DI}{ADI}$$

where:

AR = Sludge application rate (mt DW/ha)
BS = Background concentration of pollutant in soil (µg/g DW)
SC = Sludge concentration of pollutant (µg/g DW)
GS = Fraction of animal diet assumed to be soil (unitless)
UA = Uptake slope of pollutant in animal tissue (µg/g tissue DW [µg/g feed DW^{-1}]
DA = Average daily human dietary intake of affected animal tissue (g/day DW)
DI = Average daily human dietary intake of pollutant (µg/day)
ADI = Acceptable daily intake of pollutant (µg/day)

b. Sample calculation (toddler)

$$0.206 = \frac{(86.4\ \mu g/gDW \times 0.05 \times 0.03176\ \mu g/g\ tissue[\mu g/g\ feed]^{-1} \times 0.97 g/dayDW) + 825\ \mu g/day}{4000\ \mu g/day}$$

4. Index of Human Toxicity Resulting from Soil Ingestion (Index 12)

a. Formula

$$\text{Index 12} = \frac{(I_1 \times BS \times DS) + DI}{ADI}$$

$$\text{Pure sludge ingestion:} \quad \text{Index 12} = \frac{(SC \times DS) + DI}{ADI}$$

where:

I_1 = Index 1 = Index of soil concentration increment (unitless)
SC = Sludge concentration of pollutant (µg/g DW)
BS = Background concentration of pollutant in soil (µg/g DW)
DS = Assumed amount of soil in human diet (g/day)
DI = Average daily dietary intake of pollutant (µg/day)
ADI = Acceptable daily intake of pollutant (µg/day)

b. Sample calculation (toddler)

$$0.571 = \frac{(0.998 \times 292\ \mu g/g\ DW \times 5\ g\ soil/day) + 825\ \mu g/day}{4000\ \mu g/day}$$

Pure sludge:

$$0.314 = \frac{(86.4\ \mu g/g\ DW \times 5\ g\ soil/day) + 825\ \mu g/day}{4000\ \mu g/day}$$

5. Index of Aggregate Human Toxicity (Index 13)

a. Formula

$$\text{Index 13} = I_9 + I_{10} + I_{11} + I_{12} - \left(\frac{3DI}{ADI}\right)$$

where:

I_9 = Index 9 = Index of human toxicity resulting from plant consumption (unitless)
I_{10} = Index 10 = Index of human toxicity resulting from consumption of animal products derived from animals feeding on plants (unitless)
I_{11} = Index 11 = Index of human toxicity resulting from consumption of animal products derived from animals ingesting soil (unitless)
I_{12} = Index 12 = Index of human toxicity resulting from soil ingestion (unitless)
DI = Average daily dietary intake of pollutant (µg/day)
ADI = Acceptable daily intake of pollutant (µg/day)

b. **Sample calculation (toddler)**

$$0.569 = (0.205 + 0.206 + 0.206 + 0.571) - \left(\frac{3 \times 825\ \mu g/day}{4000\ \mu g/day}\right)$$

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

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.

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.