&EPA

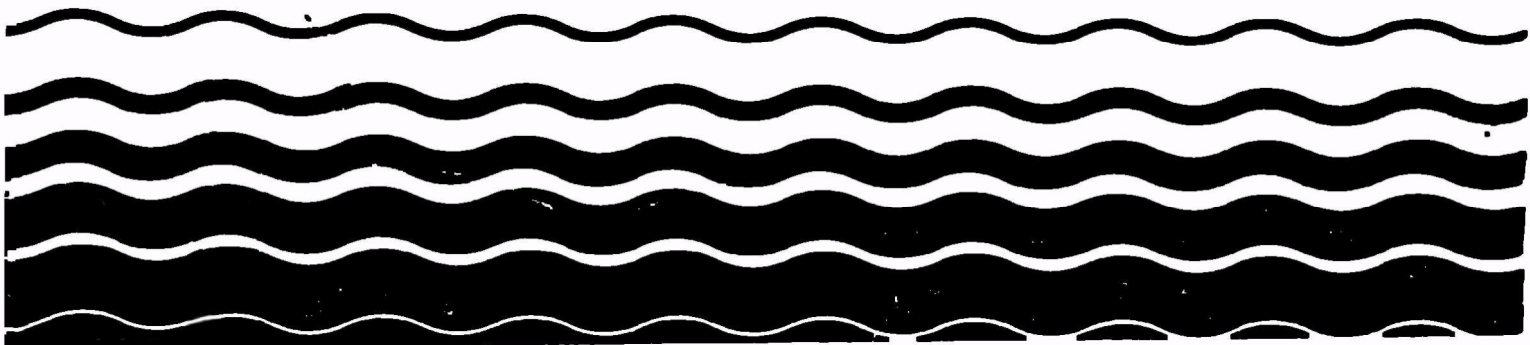# Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Cyanide

PREFACE

This document is one of a series of prelimin.. 'v 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 lands reading 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.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

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. Cyanide was initially identified as being of potential concern when sludge is placed in a landfill.* This profile is a compilation of information that may be useful in determining whether cyanide 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 ind..es" 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 → groundwater → 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 landfilling 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 CYANIDE 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 meeting (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

The landfill disposal of municipal sewage sludge is expected to result in a substantial increase in cyanide concentrations in groundwater, especially when worst-site parameters are present in the saturated zone or when the cumulative worst case is evaluated (see Index 1). In most cases, cyanide may pose a slight human health hazard as a result of drinking groundwater contaminated by municipal sewage sludge landfills. However, a moderate health hazard may be associated with the cumulative worst-case landfill scenario (see Index 2).

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.

PRELIMINARY HAZARD INDICES FOR CYANIDE
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

A. Index of Groundwater Concentration Resulting from Landfilled Sludge (Index 1)

1. Explanation - Calculates groundwater contamination which could occur in a potable aquifer in the landfill vicinity. Uses U.S. EPA's Exposure Assessment Group (EAG) model, "Rapid Assessment of Potential Groundwater Contamination Under Emergency Response Conditions" (U.S. EPA, 1983). Treats landfill leachate as a pulse input, i.e., the application of a constant source concentration for a short time period relative to the time frame of the analysis. In order to predict pollutant movement in soils and groundwater, parameters regarding transport and fate, and boundary or source conditions are evaluated. Transport parameters include the interstitial pore water velocity and dispersion coefficient. Pollutant fate parameters include the degradation/decay coefficient and retardation factor. Retardation is primarily a function of the adsorption process, which is characterized by a linear, equilibrium partition coefficient representing the ratio of adsorbed and solution pollutant concentrations. This partition coefficient, along with soil bulk density and volumetric water content, are used to calculate the retardation factor. A computer program (in FORTRAN) was developed to facilitate computation of the analytical solution. The program predicts pollutant concentration as a function of time and location in both the unsaturated and saturated zone. Separate computations and parameter estimates are required for each zone. The prediction requires evaluations of four dimensionless input values and subsequent evaluation of the result, through use of the computer program.

2. Assumptions/Limitations - Conservatively assumes that the pollutant is 100 percent mobilized in the leachate and that all leachate leaks out of the landfill in a finite period and undiluted by precipitation. Assumes that all soil and aquifer properties are homogeneous and isotropic throughout each zone; steady, uniform flow occurs only in

the vertical direction throughout the unsaturated zone, and only in the horizontal (longitudinal) plane in the saturated zone; pollutant movement is considered only in direction of groundwater flow for the saturated zone; all pollutants exist in concentrations that do not significantly affect water movement; for organic chemicals, the background concentration in the soil profile or aquifer prior to release from the source is assumed to be zero; the pollutant source is a pulse input; no dilution of the plume occurs by recharge from outside the source area; the leachate is undiluted by aquifer flow within the saturated zone; concentration in the saturated zone is attenuated only by dispersion.

3. Data Used and Rationale

a. Unsaturated zone

i. Soil type and characteristics

(a) Soil type

Typical   Sandy loam
Worst   Sandy

These two soil types were used by Gerritse et al. (1982) to measure partitioning of elements between soil and a sewage sludge solution phase. They are used here since these partitioning measurements (i.e., K_d values) are considered the best available for analysis of metal transport from landfilled sludge. The same soil types are also used for nonmetals for convenience and consistency of analysis.

(b) Dry bulk density (P_{dry})

Typical   1.53   g/mL
Worst   1.925 g/mL

Bulk density is the dry mass per unit volume of the medium (soil), i.e., neglecting the mass of the water (Camp Dresser and McKee, Inc. (CDM), 1984).

(c) Volumetric water content (θ)

Typical   0.195 (unitless)
Worst   0.133 (unitless)

The volumetric water content is the volume of water in a given volume of media, usually expressed as a fraction or percent. It depends on properties of the media and the water flux

estimated by infiltration or net recharge. The volumetric wa⎵᷉r content is used in calculating the water m vement through the unsaturated zone (pore water velocity) and the retardation coefficient. Values obtained from CDM, 1984.

(d) Fraction of organic carbon (f_{oc})

Typical   0.005 (unitless)
Worst   0.0001 (unitless)

Organic content of soils is described in terms of percent organic carbon, which is required in the estim.·ion of partition coefficient, K_d. Values, obtained from R. Griffin (1984) are representative values for subsurface soils.

ii. Site parameters

(a) Landfill leaching time (LT) = 5 years

Sikora et al. (1982) monitored several sludge entrenchment sites throughout the United States and estimated time of landfill leaching to be 4 or 5 years. Other types of landfills may leach for longer periods of time; however, the use of a value for entrenchment sites is conservative because it results in a higher leachate generation rate.

(b) Leachate generation rate (Q)

Typical   0.8 m/year
Worst   1.6 m/year

It is conservatively assumed that sludge leachate enters the unsaturated zone undiluted by precipitation or other recharge, that the total volume of liquid in the sludge leaches out of the landfill, and that leaching is complete in 5 years. Landfilled sludge is assumed to be 20 percent solids by volume, and depth of sludge in the landfill is 5 m in the typical case and 10 m in the worst case. Thus, the initial depth of liquid is 4 and 8 m, and average yearly leachate generation is 0.8 and 1.6 m, respectively.

(c) Depth to groundwater (h)

Typical   5 m
Worst   0 m

Eight landfills were monitored throughout the United States and depths to groundwater below them were listed. A typical depth to groundwater of 5 m was observed (U.S. EPA, 1977). For the worst case, a value of 0 m is used to represent the situation where the bottom of the landfill is occasionally or regularly below the water table. The depth to groundwater must be estimated in order to evaluate the likelihood that pollutants moving through the unsaturated soil will reach the groundwater.

(d) **Dispersivity coefficient (α)**

Typical   0.5 m
Worst   Not applicable

The dispersion process is exceedingly complex and difficult to quantify, especially for the unsaturated zone. It is sometimes ignored in the unsaturated zone, with the reasoning that pore water velocities are usually large enough so that pollutant transport by convection, i.e., water movement, is paramount. As a rule of thumb, dispersivity may be set equal to 10 percent of the distance measurement of the analysis (Gelhar and Axness, 1981). Thus, based on depth to groundwater listed above, the value for the typical case is 0.5 and that for the worst case does not apply since leachate moves directly to the unsaturated zone.

iii. Chemical-specific parameters

(a) **Sludge concentration of pollutant (SC)**

Typical   476.2 mg/kg DW
Worst   2686.6 mg/kg DW

The typical and worst sludge concentrations are the median and 95th percentile values, respectively, 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).

(b) **Soil half-life of pollutant ($t_{\frac{1}{2}}$)** - Data not immediately available.

(c) **Degradation rate (μ) = 0.0 day^{-1}**

The unsaturated zone can serve as an effective medium for reducing pollutant concentration through a variety of chemical and biological

decay mechanisms which transform or attenuate the pollutant. While these decay processes are usually complex, they ar approximated here by a first-order rate constai. The degradation rate is calculated using the following formula:

$$\mu = \frac{0.693}{t_{\frac{1}{2}}}$$

Since half-life data are not immediately available, it is conservatively assumed that $\mu = 0.0$ day^{-1}.

(d) **Organic carbon partition coefficient (K_{oc}) = 0.0 mL/g**

The organic carbon partition coefficient is multiplied by the percent organic carbon content of soil (f_{oc}) to derive a partition coefficient (K_d), which represents the ratio of absorbed pollutant concentration to the dissolved (or solution) concentration. The equation (K_{oc} x f_{oc}) assumes that organic carbon in the soil is the primary means of adsorbing organic compounds onto soils. This concept serves to reduce much of the variation in K_d values for different soil types. Since data are not immediately available, it is conservatively assumed that $K_{oc} = 0.0$ mL/g.

b. **Saturated zone**

i. **Soil type and characteristics**

(a) **Soil type**

Typical   Silty sand
Worst   Sand

A silty sand having the values of aquifer porosity and hydraulic conductivity defined below represents a typical aquifer material. A more conductive medium such as sand transports the plume more readily and with less dispersion and therefore represents a reasonable worst case.

(b) **Aquifer porosity ($\emptyset$)**

Typical   0.44 (unitless)
Worst   0.389 (unitless)

Porosity is that portion of the total volume of soil that is made up of voids (air) and water. Values corresponding to the above soil types

are from Pettyjohn et al. (1982) as presented in U.S. EPA (1983).

(c) Hydraulic conductivity of the aquifer (K)

Typical   0.86 m/day
Worst   4.04 m/day

The hydraulic conductivity (or permeability) of the aquifer is needed to estimate flow velocity based on Darcy's Equation. It is a measure of the volume of liquid that can flow through a unit area or media with time; values can range over nine orders of magnitude depending on the nature of the media. Heterogenous conditions produce large spatial variation in hydraulic conductivity, making estimation of a single effective value extremely difficult. Values used are from Freeze and Cherry (1979) as presented in U.S. EPA (1983).

(d) Fraction of organic carbon (f_{oc}) = 0.0 (unitless)

Organic carbon content, and therefore adsorption, is assumed to be 0 in the saturated zone.

ii. Site parameters

(a) Average hydraulic gradient between landfill and well (i)

Typical   0.001 (unitless)
Worst   0.02 (unitless)

The hydraulic gradient is the slope of the water table in an unconfined aquifer, or the piezometric surface for a confined aquifer. The hydraulic gradient must be known to determine the magnitude and direction of groundwater flow. As gradient increases, dispersion is reduced. Estimates of typical and high gradient values were provided by Donigian (1985).

(b) Distance from well to landfill (Δℓ)

Typical   100 m
Worst   50 m

This distance is the distance between a landfill and any functioning public or private water supply or livestock water supply.

(c) **Dispersivity coefficient (α)**

Typical   10 m
Worst   5 m

These values are 10 percent of the distance from well to landfill ($\Delta \ell$), which is 100 and 50 m, respectively, for typical and worst conditions.

(d) **Minimum thickness of saturated zone (B) = 2 m**

The minimum aquifer thickness represents the assumed thickness due to preexisting flow; i.e., in the absence of leachate. It is termed the minimum thickness because in the vicinity of the site it may be increased by leachate infiltration from the site. A value of 2 m represents a worst case assumption that preexisting flow is very limited and therefore dilution of the plume entering the saturated zone is negligible.

(e) **Width of landfill (W) = 112.8 m**

The landfill is arbitrarily assumed to be circular with an area of 10,000 m^2.

iii. **Chemical-specific parameters**

(a) **Degradation rate (μ) = 0 day^{-1}**

Degradation is assumed not to occur in the saturated zone.

(b) **Background concentration of pollutant in groundwater (BC) = 0 μg/L**

It is assumed that no pollutant exists in the soil profile or aquifer prior to release from the source.

4. **Index Values** - See Table 3-1.

5. **Value Interpretation** - Value equals the maximum expected groundwater concentration of pollutant, in μg/L, at the well.

6. **Preliminary Conclusion** - The landfill disposal of municipal sewage sludge is expected to result in a substantial increase in cyanide concentrations in groundwater, especially when worst-site parameters are present in the saturated zone or when the cumulative worst case is evaluated.

B. Index of Human Toxicity Resulting from Groundwater Contam~nation (Index 2)

1. Explanation - Calculates human exposure which could result from groundwater contamination. Compares exposure with acceptable daily intake (ADI) of pollutant.

2. Assumptions/Limitations - Assumes long-term exposure to maximum concentration at well at a rate of 2 L/day.

3. Data Used and Rationale

    a. Index of groundwater concentration resulting from landfilled sludge (Index 1)

        See Section 3, p. 3-9.

    b. Average human consumption of drinking water (AC) = 2 L/day

        The value of 2 L/day is a standard value used by U.S. EPA in most risk assessment studies.

    c. Average daily human dietary intake of pollutant (DI) - Data not immediately available.

    d. Acceptable daily intake of pollutant (ADI) = 7560 μg/day

        The reported ADI value is based on the no-observable-adverse-effect-level (NOAEL) in mammals (10.8 mg/kg/day) for the inhibition of cytochrome oxidase activity in rats (U.S. EPA, 1984). (See Section 4, p. 4-3.)

4. Index 2 Values - See Table 3-1.

5. Value Interpretation - Value equals factor due only to groundwater contamination by landfill by which expected intake exceeds ADI. The value does not account for the possible increase resulting from daily dietary intake of pollutant since DI data were not immediately available.

6. Preliminary Conclusion - In most cases, cyanide may pose a slight human health hazard as a result of drinking groundwater contaminated by municipal sewage sludge landfills. However, a moderate health hazard may be associated with the cumulative worst-case landfill scenario.

TABLE 3-1. INDEX OF GROUNDWATER CONCENTRATION RESULTING FROM LANDFILLED SLUDGE (INDEX 1) AND INDEX OF HUMAN TOXICITY RESULTING FROM GROUNDWATER CONTAMINATION (INDEX 2)

Site Characteristics	Condition of Analysis[a,b,c]							
	1	2	3	4	5	6	7	8
Sludge concentration	T	W	T	T	T	T	W	N
Unsaturated Zone								
Soil type and characteristics[d]	T	T	W	NA	T	T	NA	N
Site parameters[e]	T	T	T	W	T	T	W	N
Saturated Zone								
Soil type and characteristics[f]	T	T	T	T	W	T	W	N
Site parameters[g]	T	T	T	T	T	W	W	N
Index 1 Value (μg/L)	13	73	13	13	69	520	16000	0
Index 2 Value	3.4×10^{-3}	1.9×10^{-2}	3.4×10^{-3}	3.4×10^{-3}	1.8×10^{-2}	0.14	4.1	0

[a] T = Typical values used; W = worst-case values used; N = null condition, where no landfill exists, used as basis for comparison; NA = not applicable for this condition.
[b] Index values for combinations other than those shown may be calculated using the formulae in the Appendix.
[c] See Table A-1 in Appendix for parameter values used.
[d] Dry bulk density (P_{dry}), volumetric water content (θ), and fraction of organic carbon (f_{oc}).
[e] Leachate generation rate (Q), depth to groundwater (h), and dispersivity coefficient (α).
[f] Aquifer porosity ($\emptyset$) and hydraulic conductivity of the aquifer (K).
[g] Hydraulic gradient (i), distance from well to landfill ($\Delta \ell$), and dispersivity coefficient (α).

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 CYANIDE IN MUNICIPAL SEWAGE SLUDGE

I. OCCURRENCE

A. Sludge

1. Frequency of Detection

Detected in 99% of 432 samples from 40 POTWs	U.S. EPA, 1982 (p. 41)
Detected in 72% of 72 samples from 10 POTWs	U.S. EPA, 1982 (p. 49)

2. Concentration

36 to 286,000 µg/L in 40 POTWs	U.S. EPA, 1982 (p. 41)
10 to 4,000 µg/L in 10 POTWs	U.S. EPA, 1982 (p. 49)
50th percentile = 476.2 µg/g DW Mean = 835.6 µg/g DW 95th percentile = 2686.6 µg/g DW	Statistically derived from U.S. EPA, 1982

B. Soil - Unpolluted

1. Frequency of Detection

Data not immediately available.

2. Concentration

Cyanides are not absorbed or retained within soils. Microbial metabolism rapidly degrades cyanide and thus minimizes soil accumulation.	U.S. EPA, 1978 (p. 2)
Cyanide is not a natural constituent of soil. Plants can synthesize quite large amounts of cyanide in tissues under certain climatic conditions. Incorporation of cyanide-containing plant materials into soils usually results in the transformation of cyanide into harmless nitrogen gas or into nitrate by microbial oxidation.	Fuller, 1977 (p. 70)

C. Water - Unpolluted

1. Frequency of Detection

Despite numerous potential sources of   U.S. EPA, 1980
pollution, cyanide is relatively   (p. C-2)
uncommon in U.S. water supplies.

2. Concentration

a. Freshwater

Data not immediately available.

b. Seawater

Data not immediately available.

c. Drinking water

8 µg/L maximum concentration   U.S. EPA, 1982
0.09 µg/L average for 2,595 water   (p. C-4)
samples

D. Air

1. Frequency of Detection

Cyanides are uncommon in air.   U.S. EPA, 1980
                                       (p. C-1)

Cyanides are usually not found in air. U.S. EPA, 1978
                                        (p. 9)

2. Concentration

Data not immediately available.

E. Food

1. Frequency of Detection

Except for certain naturally occurring   U.S. EPA, 1982
organonitrites in plants, it is uncommon (p. C-5)
to find cyanide in foods in the United
States. Additionally, there are no data
indicating bioconcentration of cyanide.
The bioconcentration factor will be very
close to zero.

2. Concentration

Data not immediately available.

II. HUMAN EFFECTS

A. Ingestion

1. Carcinogenicity

a. Qualitative Assessment

There have been no detailed studies   U.S. EPA, 1978
to implicate cyanide as a carcino-   (p. 183)
genic agent.

b. Potency

Data not immediately available.

c. Effects

There is no evidence that chronic   U.S. EPA, 1980
exposure to cyanide results in   (p. C-23)
carcinogenic effects.

2. Chronic Toxicity

a. ADI

7.56 mg/day. The ADI for man has   U.S. EPA, 1984
been derived by taking the NOAEL in   (p. 17)
mammals (10.8 mg/kg/day) multiplied
by the weight of the average man
(70 kg) and dividing by a safety
factor of 100. This is based on
data for the inhibition of cyto-
chrome oxidase activity in rats.

b. Effects

The chronic effects of long term   U.S. EPA, 1978
exposure to low cyanide levels are   (p. 139)
not well understood.

Cyanide ingested by humans at quanti-   U.S. EPA, 1976
ties of 10 mg or less per day is not   (p. 67)
toxic and is biotransferred to the
less toxic thiocyanate.

3. Absorption Factor

The percentage of a given dose absorbed
is a factor of dose size and absorption
rate: death may intervene before
absorption is complete.

U.S. EPA, 1978
(p. 128)

4. Existing Regulations

Water quality criterion for drinking
water = 200 µg/L

U.S. EPA, 1980
(p. C-24)

B. Inhalation

1. Carcinogenicity

Data not immediately available.

2. Chronic Toxicity

a. Inhalation Threshold or MPIH

No data immediately available for
cyanide.

b. Effects

Inhalation of cyanogen or halogenated
cyanogens causes respiratory irrita-
tion with possible hemorrhage and
pulmonary edema. Inhalation of HCN
vapor can be fatal.

U.S. EPA, 1978
(p. 129)

Inhalation of 270 ppm HCN vapor
brings death immediately; 135 ppm
is fatal after 30 minutes.

U.S. EPA, 1978
(p. 129)

3. Absorption Factor

Data not immediately available.

4. Existing Regulations

Threshold limit values on the basis of
time-weighted average for cyanogen is
20 mg/m^3 or 10 ppm.

ACGIH, 1982

III. PLANT EFFECTS

A. Phytotoxicity

Cyanide is toxic to plants inhibiting
electron transport in photosynthetic and
respiratory functions.

U.S. EPA, 1978
(p. 100)

Cyanides are found in many plants and animals as metabolic intermediates which are generally not stored for long periods of time.	U.S. EPA, 1976 (p. 65)
Cyanide is naturally produced by some fungi, at least one bacterium, and many vascular plants.	Fuller, 1977 (p. 145)
Cyanide is utilized as an energy source and/ or source of nitrogen by plants and microorganisms.	
Cyanide and related compounds have long been regarded as potential fertilizers. Cyanamide serves as a fertilizer because it forms ammonia readily in soils.	
Cyanide added to soils in modest amounts (up to 200 µg/g NaCN) is slightly less effective as a N-fertilizer for some crops.	

B. Uptake

Free cyanide is not found in plants.	U.S. EPA, 1978 (p. 4)
Cyanide producing plants can have up to 378 µg/g CN in tissues.	U.S. EPA, 1978 (p. 87)

IV. DOMESTIC ANIMAL AND WILDLIFE EFFECTS

A. Toxicity

See Table 4-1.

Cyanide has an unusually low degree of chronic toxicity. It does not appear to be mutagenic, teratogenic, or carcinogenic.	U.S. EPA, 1980 (p. C-2)

B. Uptake

Cyanide has a low degree of persistence in the environment and it is not accumulated or stored in any mammalian species that has been studied.	U.S. EPA, 1980 (p. C-1)
There is no data available indicating bioconcentration of cyanide. The U.S. EPA Duluth laboratory states that the bioconcentration factor will be very close to zero.	U.S. EPA, 1980 (p. C-5)

Cyanides are found in many plants and animals
as metabolic intermediates which are
generally not stored for long periods of
time.

V. AQUATIC LIFE EFFECTS

A. Toxicity

1. Freshwater

Freshwater aquatic organisms and their   U.S. EPA, 1985
uses should not be affected unaccep-
tably if the four-day average concen-
tration of free cyanide (the sum of
cyanide present as HCN and CN^{-1},
expressed as CN) does not exceed
5.2 µg/L more than once every three
years on the average and if the one-
hour average concentration does not
exceed 22 µg/L more than once every
three years on the average.

2. Saltwater

Saltwater aquatic organisms and their   U.S. EPA, 1985
uses should not be affected unaccep-
tably if the one-hour average concen-
tration of free cyanide (the sum of
cyanide present as HCN and CN^{-1},
expressed as CN) does not exceed
1.0 µg/L more than once every three
years on the average.

B. Uptake

Data not immediately available.

VI. SOIL BIOTA EFFECTS

A. Toxicity

See Table 4-2.

A wide variety of microorganisms are able   U.S. EPA, 1978
to metabolize cyanide. These organisms may   (p. 3)
play a role in the treatment of cyanide
wastes. If a mixed population in a sludge
sample has not been exposed to cyanide
concentration, small cyanide concentration
(200 ppm) can be toxic. However, the popula-
tion can be acclimated to cyanide after which
higher concentrations can be metabolized.

B. Uptake

Data not immediately available.

VII. PHYSICOCHEMICAL DATA FOR ESTIMATING FATE AND TRANSPORT

Molecular weight: HCN   27
                  CN^- 26

Physical form at standard temperature and pressure: colorless liquid

Solution in water: soluble in all proportions

Vapor pressure:

-178°C	100	torr
7°C	380	torr
21.9°C	658.7	torr
26.7°C (b.p.)	760	torr

Cyanide commonly occurs in water as hydro-cyanic acid (HCN), the cyanide ion (CN^{-1}), simple cyanides, metallocyanide complexes, or as simple chain and complex ring organic compounds. "Free cyanide" is defined as the sum of the cyanide present as HCN and as CN^{-1}. The alkali metal salts such as potassium cyanide (KCN) and sodium cyanide (NaCN) are very soluble in aqueous solutions and the resulting cyanide ions readily hydrolyze with water to form HCN. The extent of HCN formation is mainly dependent upon water temperature and pH. At 20°C and a pH of 8 or below, the fraction of free cyanide existing as HCN is at least 0.96.

Cyanide ions form complexes with a variety of metals, especially those of the transition series. The stabilities of these complexes are highly variable. Zinc and cadmium cyanide complexes, when diluted with water, are known to dissociate rapidly and nearly completely to form HCN. Some of the other metallocyanide anions, such as those formed with copper, nickel, and iron, demonstrate varying degrees of stability.

U.S. EPA, 1980

TABLE 4-1. TOXICITY OF CYANIDE 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
Dog	NaCN	NR[a]	NR	0.5-2.0	15 months	Administered once or twice per day producing toxic signs but recovery within 1/2 hour; no long-term effects	U.S. EPA, 1980 (p. C-18)
Dog, beagle	NaCN	150	NR	NR	30 days	No effect	U.S. EPA, 1980 (p. C-19)
Rat	HCN fumigated into feed	100-300	NR	NR	2 years	No effect	U.S. EPA, 1980 (p. C-19)

[a] NR = Not reported.

TABLE 4-2. TOXICITY OF CYANIDE TO SOIL BIOTA

Species	Chemical Form Applied	Soil Type	Experimental Tissue Concentration (µg/g)	Experimental Soil Concentration (µg/g)	Experimental Application Rate (kg/ha)	Tissue Concentration (µg/g)	Effects	References
Nitrifying bacteria	Cyanide	Calcareous	NR[a]	100 of N	NR	NR	No effect on rate of nitrogen conversion	Fuller, 1977 (p. 145)
Nitrifying bacteria	Cyanide	Calcareous	NR	200 of N	NR		50% reduction in nitrogen conversion	Fuller, 1977 (p. 145)
Nitrifying bacteria	CN	NR	NR	<200	NR	NR	Readily transformed or degraded depending on oxidation/ reduction conditions	Fuller, 1977 (p. 146)

[a] NR = Not reported.

SECTION 5

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APPENDIX

PRELIMINARY HAZARD INDEX CALCULATIONS FOR CYANIDE 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

A. Procedure

Using Equation 1, several values of C/C_o for the unsaturated zone are calculated corresponding to increasing values of t until equilibrium is reached. Assuming a 5-year pulse input from the landfill, Equation 3 is employed to estimate the concentration vs. time data at the water table. The concentration vs. time curve is then transformed into a square pulse having a constant concentration equal to the peak concentration, C_u, from the unsaturated zone, and a duration, t_o, chosen so that the total areas under the curve and the pulse are equal, as illustrated in Equation 3. This square pulse is then used as the input to the linkage assessment, Equation 2, which estimates initial dilution in the aquifer to give the initial concentration, C_o, for the saturated zone assessment. (Conditions for B, minimum thickness of unsaturated zone, have been set such that dilution is actually negligible.) The saturated zone assessment procedure is nearly identical to that for the unsaturated zone except for the definition of certain parameters and choice of parameter values. The maximum concentration at the well, C_{max}, is used to calculate the index values given in Equations 4 and 5.

B. Equation 1: Transport Assessment

$$\frac{C(\chi,t)}{C_o} = \tfrac{1}{2} \left[\exp(A_1)\, erfc(A_2) + \exp(B_1)\, erfc(B_2) \right] = P(\chi,t)$$

Requires evaluations of four dimensionless input values and subsequent evaluation of the result. $Exp(A_1)$ denotes the exponential of A_1, e^{A_1}, where $erfc(A_2)$ denotes the complimentary error function of A_2. $Erfc(A_2)$ produces values between 0.0 and 2.0 (Abramowitz and Stegun, 1972).

where:

$$A_1 = \frac{\chi}{2D*} \left[V* - (V*^2 + 4D* \times \mu*)^{\frac{1}{2}} \right]$$

$$A_2 = \frac{\chi - t \, (V*^2 + 4D* \times \mu*)^{\frac{1}{2}}}{(4D* \times t)^{\frac{1}{2}}}$$

$$B_1 = \frac{\chi}{2D*} \left[V* + (V*^2 + 4D* \times \mu*)^{\frac{1}{2}} \right]$$

$$B_2 = \frac{\chi + t \, (V*^2 + 4D* \times \mu*)^{\frac{1}{2}}}{(4D* \times t)^{\frac{1}{2}}}$$

and where for the unsaturated zone:

C_0 = SC x CF = Initial leachate concentration (μg/L)
SC = Sludge concentration of pollutant (mg/kg DW)
CF = 250 kg sludge solids/m^3 leachate =

$$\frac{PS \times 10^3}{1 - PS}$$

PS = Percent solids (by weight) of landfilled sludge = 20%
t = Time (years)
χ = h = Depth to groundwater (m)
D* = α x V* (m^2/year)
α = Dispersivity coefficient (m)

$$V* = \frac{Q}{\Theta \times R} \text{ (m/year)}$$

Q = Leachate generation rate (m/year)
Θ = Volumetric water content (unitless)

$$R = 1 + \frac{P_{dry}}{\Theta} \times K_d = \text{Retardation factor (unitless)}$$

P_{dry} = Dry bulk density (g/mL)
K_d = f_{oc} x K_{oc} (mL/g)
f_{oc} = Fraction of organic carbon (unitless)
K_{oc} = Organic carbon partition coefficient (mL/g)

$$\mu* = \frac{365 \times \mu}{R} \text{ (years)}^{-1}$$

μ = Degradation rate (day^{-1})

and where for the saturated zone:

C_0 = Initial concentration of pollutant in aquifer as determined by Equation 2 (μg/L)
t = Time (years)
χ = $\Delta \ell$ = Distance from well to landfill (m)
D* = α x V* (m^2/year)
α = Dispersivity coefficient (m)

$$V^* = \frac{K \times i}{\emptyset \times R} \text{ (m/year)}$$

K = Hydraulic conductivity of the aquifer (m/day)

i = Average hydraulic gradient between landfill and well (unitless)

$\emptyset$ = Aquifer porosity (unitless)

$$R = 1 + \frac{P_{dry}}{\emptyset} \times K_d = \text{Retardation factor} = 1 \text{ (unitless)}$$

since $K_d = f_{oc} \times K_{oc}$ and f_{oc} is assumed to be zero for the saturated zone.

C. Equation 2. Linkage Assessment

$$C_o = C_u \times \frac{Q \times W}{365 \ [(K \times i) \div \emptyset] \times B}$$

where:

C_o = Initial concentration of pollutant in the saturated zone as determined by Equation 1 (μg/L)

C_u = Maximum pulse concentration from the unsaturated zone (μg/L)

Q = Leachate generation rate (m/year)

W = Width of landfill (m)

K = Hydraulic conductivity of the aquifer (m/day)

i = Average hydraulic gradient between landfill and well (unitless)

$\emptyset$ = Aquifer porosity (unitless)

B = Thickness of saturated zone (m) where:

$$B \geq \frac{Q \times W \times \emptyset}{K \times i \times 365} \text{ and } B \geq 2$$

D. Equation 3. Pulse Assessment

$$\frac{C(\chi,t)}{C_o} = P(\chi,t) \text{ for } 0 \leq t \leq t_o$$

$$\frac{C(\chi,t)}{C_o} = P(\chi,t) - P(\chi,t - t_o) \text{ for } t > t_o$$

where:

t_o (for unsaturated zone) = LT = Landfill leaching time (years)

t_o (for saturated zone) = Pulse duration at the water table (χ = h) as determined by the following equation:

$$t_o = [\int_o^\infty C \ dt] \div C_u$$

$$P(\chi,t) = \frac{C(\chi,t)}{C_o} \text{ as determined by Equation 1} \quad .$$

E. **Equation 4. Index of Groundwater Concentration Resulting from Landfilled Sludge (Index 1)**

1. **Formula**

   $$\text{Index 1} = C_{max}$$

   where:

   C_{max} = Maximum concentration of pollutant at well = maximum of $C(\Delta\ell,t)$ calculated in Equation 1 ($\mu g/L$)

2. **Sample Calculation**

   $$12.9 \ \mu g/L = 12.9 \ \mu g/L$$

F. **Equation 5. Index of Human Toxicity Resulting from Groundwater Contamination (Index 2)**

1. **Formula**

   $$\text{Index 2} = \frac{(I_1 \times AC) + DI}{ADI}$$

   where:

   I_1 = Index 1 = Index of groundwater concentration resulting from landfilled sludge ($\mu g/L$)
   AC = Average human consumption of drinking water (L/day)
   DI = Average daily human dietary intake of pollutant ($\mu g/day$)
   ADI = Acceptable daily intake of pollutant ($\mu g/day$)

2. **Sample Calculation**

   $$0.0034246095 = \frac{(12.945024 \ \mu g/L \times 2 \ L/day)}{7560 \ \mu g/day}$$

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.

TABLE A-1. INPUT DATA VARYING IN LANDFILL ANALYSIS AND RESULT FOR EACH CONDITION

Input Data	Condition of Analysis							
	1	2	3	4	5	6	7	8
Sludge concentration of pollutant, SC (μg/g DW)	476.2	2686.6	476.2	476.2	476.2	476.2	2686.6	N[a]
Unsaturated zone								
Soil type and characteristics								
Dry bulk density, P_{dry} (g/mL)	1.53	1.53	1.925	NA[b]	1.5;	1.53	NA	N
Volumetric water content, θ (unitless)	0.195	0.195	0.133	NA	0.195	0.195	NA	N
Fraction of organic carbon, f_{oc} (unitless)	0.005	0.005	0.0001	NA	0.005	0.005	NA	P
Site parameters								
Leachate generation rate, Q (m/year)	0.8	0.8	0.8	1.6	0.8	0.8	1.6	N
Depth to groundwater, h (m)	5	5	5	0	5	5	0	N
Dispersivity coefficient, α (m)	0.5	0.5	0.5	NA	0.5	0.5	NA	N
Saturated zone								
Soil type and characteristics								
Aquifer porosity, ∅ (unitless)	0.389	0.389	0.389	0.389	0.371	0.389	0.371	N
Hydraulic conductivity of the aquifer, K (m/day)	4.04	4.04	4.04	4.04	3.29	4.04	3.29	N
Site parameters								
Hydraulic gradient, i (unitless)	0.02	0.02	0.02	0.02	0.02	0.0005	0.0005	N
Distance from well to landfill, Δℓ (m)	100	100	100	100	100	50	50	N
Dispersivity coefficient, α (m)	10	10	10	10	10	5	5	N

Results	Condition of Analysis							
	1	2	3	4	5	6	7	8
Unsaturated zone assessment (Equations 1 and 3)								
Initial leachate concentration, C_O (μg/L)	119000	672000	19000	119000	119000	119000	672000	N
Peak concentration, C_u (μg/L)	119000	672000	19000	119000	119000	119000	672000	N
Pulse duration, t_O (years)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	N
Linkage assessment (Equation 2)								
Aquifer thickness, B (m)	126	126	126	253	23.8	6.32	2.38	N
Initial concentration in saturated zone, C_O (μg/L)	119000	672000	119000	119000	119000	119000	672000	N
Saturated zone assessment (Equations 1 and 3)								
Maximum well concentration, C_{max} (μg/L)	12.9	73.0	12.9	12.9	68.8	518	15500	N
Index of groundwater concentration resulting from landfilled sludge, Index 1 (μg/L) (Equation 4)	12.9	73.0	12.9	12.9	68.8	518	15500	0
Index of human toxicity resulting from groundwater contamination, Index 2 (unitless) (Equation 5)	3.42×10^{-3}	1.93×10^{-2}	3.42×10^{-3}	3.42×10^{-3}	1.82×10^{-2}	0.137	4.11	0

[a]N = Null condition, where no landfill exists; no value is used.
[b]NA = Not applicable for this condition.

A-7