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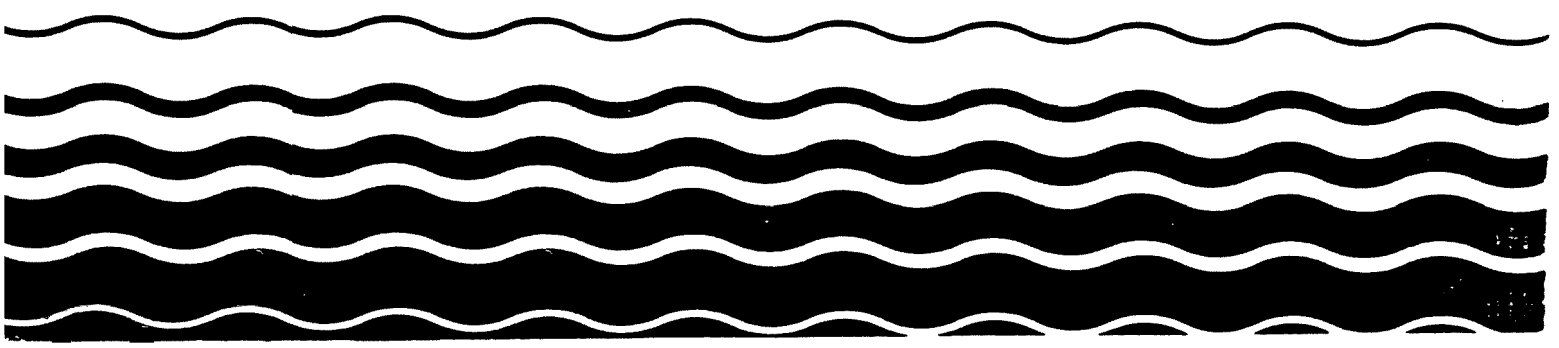
Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Chlorinated Dibenzofurans



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. Tetrachlorodibenzofurans (TCDFs) were initially identified as being of potential concern when sludge is incinerated or ocean disposed.* This profile is a compilation of information that may be useful in determining whether TCDFs pose an actual hazard to human health or the environment when sludge is disposed of by these methods.

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

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

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

The preliminary hazard indices for selected exposure routes pertinent to incineration and ocean disposal 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 TETRACHLORODIBENZOFURANS IN MUNICIPAL SEWAGE SLUDGE

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

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

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

II. LANDFILLING

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

III. INCINERATION

Conclusions were not drawn because index values could not be calculated due to lack of data.

IV. OCEAN DISPOSAL

Conclusions were not drawn because index values could not be calculated due to lack of data.

SECTION 3

PRELIMINARY HAZARD INDICES FOR TETRACHLORODIBENZOFURANS IN MUNICIPAL SEWAGE SLUDGE

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

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

II. LANDFILLING

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

III. INCINERATION

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

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

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

3. **Data Used and Rationale**

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

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

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

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

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

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

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

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

c. **Sludge concentration of pollutant (SC)** - Data not immediately available.

Concentrations of TCDFs in municipal sewage sludge were not analyzed in the U.S. EPA (1982a) study of 50 publicly-owned treatment works (POTWs) and were not available for sludge data for POTWs located throughout the United States (CDM, 1984b).

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

Typical	0.05 (unitless)
Worst	0.20 (unitless)

These values were chosen as best approximations of the fraction of pollutant emitted through stacks (Farrell, 1984). No data was available to validate these values; however, U.S. EPA is currently testing incinerators for organic emissions.

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

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

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

f. **Background concentration of pollutant in urban air (BA) = 0.0000001 $\mu g/m^3$**

Assuming that polychlorinated biphenyl (PCB) is contaminated with ~1.25 ppm TCDFs, and that ambient air concentration of PCB is 100 ng/m^3, an ambient air concentration for TCDFs of 0.0000001 $\mu g/m^3$ can be estimated (U.S. EPA, 1983). (See Section 4, p. 4-1.)

4. **Index 1 Values** - Values were not calculated due to lack of data.

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

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

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

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

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

3. **Data Used and Rationale**

a. **Index of air concentration increment resulting from incinerator emissions (Index 1)** - Values were not calculated due to lack of data.

See Section 3, p. 3-3.

b. **Background concentration of pollutant in urban air (BA)** = 0.0000001 $\mu g/m^3$

See Section 3, p. 3-3.

c. **Cancer potency** - Data not immediately available.

d. **Exposure criterion (EC)** - Data not immediately available.

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

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

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

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

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

IV. OCEAN DISPOSAL

For the purpose of evaluating pollutant effects upon and/or subsequent uptake by marine life as a result of sludge disposal, two types of mixing were modeled. The initial mixing or dilution shortly after dumping of a single load of sludge represents a high, pulse concentration to which organisms may be exposed for short time periods but which could be repeated frequently; i.e., every time a recently dumped plume is encountered. A subsequent additional degree of mixing can be expressed by a further dilution. This is defined as the average dilution occurring when a day's worth of sludge is dispersed by 24 hours of current movement and represents the time-weighted average exposure concentration for organisms in the disposal area. This dilution accounts for 8 to 12 hours of the high pulse concentration encountered by the organisms during daylight disposal operations and 12 to 16 hours of recovery (ambient water concentration) during the night when disposal operations are suspended.

A. Index of Seawater Concentration Resulting from Initial Mixing of Sludge (Index 1)

1. **Explanation** - Calculates increased concentrations in µg/L of pollutant in seawater around an ocean disposal site assuming initial mixing.

2. **Assumptions/Limitations** - Assumes that the background seawater concentration of pollutant is unknown or zero. The index also assumes that disposal is by tanker and that the daily amount of sludge disposed is uniformly distributed along a path transversing the site and perpendicular to the current vector. The initial dilution volume is assumed to be determined by path length, depth to the pycnocline (a layer separating surface and deeper water masses), and an initial plume width defined as the width of the plume four hours after dumping. The seasonal disappearance of the pycnocline is not considered.

3. **Data Used and Rationale**

   a. **Disposal conditions**

	Sludge Disposal Rate (SS)	Sludge Mass Dumped by a Single Tanker (ST)	Length of Tanker Path (L)
Typical	825 mt DW/day	1600 mt WW	8000 m
Worst	1650 mt DW/day	3400 mt WW	4000 m

The typical value for the sludge disposal rate assumes that 7.5×10^6 mt WW/year are available for dumping from a metropolitan coastal area. The conversion to

dry weight assumes 4 percent solids by weight. The worst-case value is an arbitrary doubling of the typical value to allow for potential future increase.

The assumed disposal practice to be followed at the model site representative of the typical case is a modification of that proposed for sludge disposal at the formally designated 12-mile site in the New York Bight Apex (City of New York, 1983). Sludge barges with capacities of 3400 mt WW would be required to discharge a load in no less than 53 minutes traveling at a minimum speed of 5 nautical miles (9260 m) per hour. Under these conditions, the barge would enter the site, discharge the sludge over 8180 m and exit the site. Sludge barges with capacities of 1600 mt WW would be required to discharge a load in no less than 32 minutes traveling at a minimum speed of 8 nautical miles (14,816 m) per hour. Under these conditions, the barge would enter the site, discharge the sludge over 7902 m and exit the site. The mean path length for the large and small tankers is 8041 m or approximately 8000 m. Path length is assumed to lie perpendicular to the direction of prevailing current flow. For the typical disposal rate (SS) of 825 mt DW/day, it is assumed that this would be accomplished by a mixture of four 3400 mt WW and four 1600 mt WW capacity barges. The overall daily disposal operation would last from 8 to 12 hours. For the worst-case disposal rate (SS) of 1650 mt DW/day, eight 3400 mt WW and eight 1600 mt WW capacity barges would be utilized. The overall daily disposal operation would last from 8 to 12 hours. For both disposal rate scenarios, there would be a 12 to 16 hour period at night in which no sludge would be dumped. It is assumed that under the above described disposal operation, sludge dumping would occur every day of the year.

The assumed disposal practice at the model site representative of the worst case is as stated for the typical site, except that barges would dump half their load along a track, then turn around and dispose of the balance along the same track in order to prevent a barge from dumping outside of the site. This practice would effectively halve the path length compared to the typical site.

b. **Sludge concentration of pollutant (SC)** - Data not immediately available.

See Section 3, p. 3-2.

c. **Disposal site characteristics**

	Depth to pycnocline (D)	Average current velocity at site (V)
Typical	20 m	9500 m/day
Worst	5 m	4320 m/day

Typical site values are representative of a large, deep-water site with an area of about 1500 km^2 located beyond the continental shelf in the New York Bight. The pycnocline value of 20 m chosen is the average of the 10 to 30 m pycnocline depth range occurring in the summer and fall; the winter and spring disappearance of the pycnocline is not considered and so represents a conservative approach in evaluating annual or long-term impact. The current velocity of 11 cm/sec (9500 m/day) chosen is based on the average current velocity in this area (CDM, 1984c).

Worst-case values are representative of a near-shore New York Bight site with an area of about 20 km^2. The pycnocline value of 5 m chosen is the minimum value of the 5 to 23 m depth range of the surface mixed layer and is therefore a worst-case value. Current velocities in this area vary from 0 to 30 cm/sec. A value of 5 cm/sec (4320 m/day) is arbitrarily chosen to represent a worst-case value (CDM, 1984d).

4. **Factors Considered in Initial Mixing**

When a load of sludge is dumped from a moving tanker, an immediate mixing occurs in the turbulent wake of the vessel, followed by more gradual spreading of the plume. The entire plume, which initially constitutes a narrow band the length of the tanker path, moves more-or-less as a unit with the prevailing surface current and, under calm conditions, is not further dispersed by the current itself. However, the current acts to separate successive tanker loads, moving each out of the immediate disposal path before the next load is dumped.

Immediate mixing volume after barge disposal is approximately equal to the length of the dumping track with a cross-sectional area about four times that defined by the draft and width of the discharging vessel (Csanady, 1981, as cited in NOAA, 1983). The resulting plume is initially 10 m deep by 40 m wide (O'Connor and Park, 1982, as cited in NOAA, 1983). Subsequent spreading of plume band width occurs at an average rate

of approximately 1 cm/sec (Csanady et al., 1979, as cited in NOAA, 1983). Vertical mixing is limited by the depth of the pycnocline or ocean floor, whichever is shallower. Four hours after disposal, therefore, average plume width (W) may be computed as follows:

W = 40 m + 1 cm/sec x 4 hours x 3600 sec/hour x 0.01 m/cm = 184 m = approximately 200 m

Thus the volume of initial mixing is defined by the tanker path, a 200 m width, and a depth appropriate to the site. For the typical (deep water) site, this depth is chosen as the pycnocline value of 20 m. For the worst (shallow water) site, a value of 10 m was chosen. At times the pycnocline may be as shallow as 5 m, but since the barge wake causes initial mixing to at least 10 m, the greater value was used.

5. **Index 1 Values (µg/L)** - Values cannot be calculated due to lack of data on detection limits for TCDFs in sludge. If this information were available, all null values would be 0, and all other values would be expressed in the form of "less than".

6. **Value Interpretation** - Value equals the expected increase in TCDF concentration in seawater around a disposal site as a result of sludge disposal after initial mixing.

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

B. **Index of Seawater Concentration Representing a 24-Hour Dumping Cycle (Index 2)**

1. **Explanation** - Calculates increased effective concentrations in µg/L of pollutant in seawater around an ocean disposal site utilizing a time weighted average (TWA) concentration. The TWA concentration is that which would be experienced by an organism remaining stationary (with respect to the ocean floor) or moving randomly within the disposal vicinity. The dilution volume is determined by the tanker path length and depth to pycnocline or, for the shallow water site, the 10 m effective mixing depth, as before, but the effective width is now determined by current movement perpendicular to the tanker path over 24 hours.

2. **Assumptions/Limitations** - Incorporates all of the assumptions used to calculate Index 1. In addition, it is assumed that organisms would experience high-pulsed sludge concentrations for 8 to 12 hours per day and then experience recovery (no exposure to sludge) for 12 to 16 hours per day. This situation can be expressed by the use of a TWA concentration of sludge constituent.

3. **Data Used and Rationale**

See Section 3, pp. 3-5 to 3-7.

4. **Factors Considered in Determining Subsequent Additional Degree of Mixing (Determination of TWA Concentrations)**

See Section 3, p. 3-8.

5. **Index 2 Values (µg/L)** - Values cannot be calculated due to lack of data on detection limits for TCDFs in sludge. If this information were available, all null values would be 0, and all other values would be expressed in the form of "less than".

6. **Value Interpretation** - Value equals the effective increase in TCDF concentration expressed as a TWA concentration in seawater around a disposal site experienced by an organism over a 24-hour period.

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

C. **Index of Toxicity to Aquatic Life (Index 3)**

1. **Explanation** - Compares the effective increased concentration of pollutant in seawater around the disposal site resulting from the initial mixing of sludge (Index 1) with the marine ambient water quality criterion of the pollutant, or with another value judged protective of marine aquatic life. For TCDFs, this value is the criterion that will protect marine aquatic organisms from both acute and chronic toxic effects.

   Wherever a short-term, "pulse" exposure may occur as it would from initial mixing, it is usually evaluated using the "maximum" criteria values of EPA's ambient water quality criteria methodology. However, under this scenario, because the pulse is repeated several times daily on a long-term basis, potentially resulting in an accumulation of injury, it seems more appropriate to use values designed to be protective against chronic toxicity. Therefore, to evaluate the potential for adverse effects on marine life resulting from initial mixing concentrations, as quantified by Index 1, the chronically derived criteria values are used.

2. **Assumptions/Limitations** - In addition to the assumptions stated for Indices 1 and 2, assumes that all of the released pollutant is available in the water column to move through predicted pathways (i.e., sludge to seawater to aquatic organism to man). The possibility of effects arising from accumulation in the sediments is neglected since the U.S. EPA presently lacks a satisfactory method for deriving sediment criteria.

3. **Data Used and Rationale**

   a. **Concentration of pollutant in seawater around a disposal site (Index 1)** - Values could not be calculated due to lack of data.

      See Section 3, p. 3-8.

   b. **Ambient water quality criterion (AWQC)** = 1,800 µg/L

      The criterion is based on acute toxicity results for one species of saltwater fish. Data necessary to derive chronic toxicity criterion are not presently available (U.S. EPA, 1982b).

4. **Index 3 Values** - Values could not be calculated due to lack of Index 1 values.

5. **Value Interpretation** - Value would equal the factor by which the expected seawater concentration increase in TCDFs exceeds the marine water quality criterion. A value >1 would indicate that a toxic hazard might exist for aquatic life.

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

D. **Index of Human Cancer Risk Resulting from Seafood Consumption (Index 4)**

1. **Explanation** - Estimates the expected increase in human pollutant intake associated with the consumption of seafood, a fraction of which originates from the disposal site vicinity, and compares the total expected pollutant intake with the cancer risk-specific intake (RSI) of the pollutant.

2. **Assumptions/Limitations** - In addition to the assumptions listed for Indices 1 and 2, assumes that the seafood tissue concentration increase can be estimated from the increased water concentration (Index 2) by a bioconcentration factor. It also assumes that, over the long term, the seafood catch from the disposal site vicinity will be diluted to some extent by the catch from uncontaminated areas.

3. **Data Used and Rationale**

   a. **Concentration of pollutant in seawater around a disposal site (Index 2)** - Values could not be calculated due to lack of data.

      See Section 3, p. 3-9.

Since biconcentration is a dynamic and reversible process, it is expected that uptake of sludge pollutants by marine organisms at the disposal site will reflect TWA concentrations, as quantified by Index 2, rather than pulse concentrations.

b. Dietary consumption of seafood (QF)

Typical	14.3 g WW/day
Worst	41.7 g WW/day

Typical and worst-case values are the mean and the 95th percentile, respectively, for all seafood consumption in the United States (Stanford Research Institute (SRI) International, 1980).

c. Fraction of consumed seafood originating from the disposal site (FS)

For a typical harvesting scenario, it was assumed that the total catch over a wide region is mixed by harvesting, marketing and consumption practices, and that exposure is thereby diluted. Coastal areas have been divided by the National Marine Fishery Service (NMFS) into reporting areas for reporting on data on seafood landings. Therefore it was convenient to express the total area affected by sludge disposal as a fraction of an NMFS reporting area. The area used to represent the disposal impact area should be an approximation of the total ocean area over which the average concentration defined by Index 2 is roughly applicable. The average rate of plume spreading of 1 cm/sec referred to earlier amounts to approximately 0.9 km/day. Therefore, the combined plume of all sludge dumped during one working day will gradually spread, both parallel to and perpendicular to current direction, as it proceeds down-current. Since the concentration has been averaged over the direction of current flow, spreading in this dimension will not further reduce average concentration; only spreading in the perpendicular dimension will reduce the average. If stable conditions are assumed over a period of days, at least 9 days would be required to reduce the average concentration by one-half. At that time, the original plume length of approximately 8 km (8000 m) will have doubled to approximately 16 km due to spreading.

It is probably unnecessary to follow the plume further since storms, which would result in much more rapid dispersion of pollutants to background concentrations are expected on at least a 10-day frequency (NOAA, 1983). Therefore, the area

impacted by sludge disposal (AI, in km^2) at each disposal site will be considered to be defined by the tanker path length (L) times the distance of current movement (V) during 10 days, and is computed as follows:

$$AI = 10 \times L \times V \times 10^{-6}\ km^2/m^2 \qquad (1)$$

To be consistent with a conservative approach, plume dilution due to spreading in the perpendicular direction to current flow is disregarded. More likely, organisms exposed to the plume in the area defined by equation 1 would experience a TWA concentration lower than the concentration expressed by Index 2.

Next, the value of AI must be expressed as a fraction of an NMFS reporting area. In the New York Bight, which includes NMFS areas 612-616 and 621-623, deep-water area 623 has an area of approximately 7200 km^2 and constitutes approximately 0.02 percent of the total seafood landings for the Bight (CDM, 1984c). Near-shore area 612 has an area of approximately 4300 km^2 and constitutes approximately 24 percent of the total seafood landings (CDM, 1984d). Therefore the fraction of all seafood landings (FS_t) from the Bight which could originate from the area of impact of either the typical (deep-water) or worst (near-shore) site can be calculated for this typical harvesting scenario as follows:

For the typical (deep water) site:

$$FS_t = \frac{AI \times 0.02\%}{7200\ km^2} = \qquad (2)$$

$$\frac{[10 \times 8000\ m \times 9500\ m \times 10^{-6}\ km^2/m^2] \times 0.0002}{7200\ km^2} = 2.1 \times 10^{-5}$$

For the worst (near shore) site:

$$FS_t = \frac{AI \times 24\%}{4300\ km^2} = \qquad (3)$$

$$\frac{[10 \times 4000\ m \times 4320\ m \times 10^{-6}\ km^2/m^2] \times 0.24}{4300\ km^2} = 9.6 \times 10^{-3}$$

To construct a worst-case harvesting scenario, it was assumed that the total seafood consumption for an individual could originate from an area more limited than the entire New York Bight. For example, a particular fisherman providing the entire seafood diet for himself or others could fish

habitually within a single NMFS reporting area. Or, an individual could have a preference for a particular species which is taken only over a more limited area, here assumed arbitrarily to equal an NMFS reporting area. The fraction of consumed seafood (FS_w) that could originate from the area of impact under this worst-case scenario is calculated as follows:

For the typical (deep water) site:

$$FS_w = \frac{AI}{7200\ km^2} = 0.11 \qquad (4)$$

For the worst (near shore) site:

$$FS_w = \frac{AI}{4300\ km^2} = 0.040 \qquad (5)$$

d. **Bioconcentration factor of pollutant (BCF)** - Data not immediately available.

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

f. **Cancer potency** - Data not immediately available.

g. **Cancer risk-specific intake (RSI)** - Data not immediately available.

The RSI is the pollutant intake value which results in an increase in cancer risk of 10^{-6} (1 per 1,000,000). The RSI is calculated from the cancer potency using the following formula:

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

4. **Index 4 Values** - Values could not be calculated due to lack of data.

5. **Value Interpretation** - Value >1 would indicate a potentially toxic hazard for humans. Comparison with the null index value at 0 mt/day would indicate the degree to which any hazard is due to sludge disposal, as opposed to preexisting dietary sources.

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

SECTION 4

PRELIMINARY DATA PROFILE FOR TETRACHLORODIBENZOFURANS IN MUNICIPAL SEWAGE SLUDGE

I. OCCURRENCE

The halogenated dibenzofurans (DBFs) entered the environment as unintentional impurities in polychlorinated biphenyls (PCBs) and products derived from chlorophenols and chlorobenzenes, as well as being pyrolysis and photochemical products of PCBs and probably polychlorinated diphenylethers (PCDPEs). The alkyl DBFs and unsubstituted DBFs are pyrolysis products of coal conversion. Both alkyl and halogenated DBFs have been implicated as resulting from trace residues of fire, most notably incineration of anthropogenic wastes. — U.S. EPA, 1982b (p. vi)

A. Sludge

Data not immediately available.

B. Soil - Unpolluted

Data not immediately available.

C. Water - Unpolluted

2.4×10^{-6} µg/L interim ambient water criterion for protection of human health from the toxic properties of halogenated DBFs ingested through water or contaminated aquatic organisms. — U.S. EPA, 1982b (p. 1-2)

D. Air

No data available on ambient concentrations of DBFs.

A sample of polychlorinated biphenyl (PCB) was shown to contain ~1.25 ppm TCDF. If the ratio of TCDF to PCB is assumed to be the same in air as in the measured PCB, and the ambient air concentration of PCP is ~100 ng/m^3, then an ambient air concentration of 0.0000001 µg/m^3 TCDF can be estimated. — U.S. EPA, 1983 (p. 3-3)

Fly ash contains traces (100 ng/g or less) of DBFs. — U.S. EPA, 1982b (p. 13-2)

0.3 and 0.1 µg/g PCDFs in 2 fly ash samples from a municipal incinerator	Buser et al., 1978 (p. 426)
Flue gas has been shown to contain PCDFs.	Buser et al., 1978 (p. 428)

E. Food

TCDFs have been detected in fish collected from the Ohio and Hudson Rivers. An estimate of dietary consumption of 2,3,7,8-TCDF resulting from fish consumption equals 0.2 µg/day.	U.S. EPA, 1983 (p. 3-1)

II. HUMAN EFFECTS

A. Ingestion

1. Carcinogenicity

a. Qualitative Assessment

There is no experimental evidence to suggest that any of the halogenated dibenzofurans are carcinogenic. However, the similarities in structure, and biological effects between TCDDs, which are regarded as being carcinogenic, and TCDFs raise the suspicion that TCDFs may be carcinogenic.	U.S. EPA, 1983 (p. 5-1)

b. Potency

Data not immediately available.

c. Effects

Data not immediately available.

2. Chronic Toxicity

a. ADI

Data not immediately available.

b. Effects

Approximately 1,200 Japanese people ingested rice oil which was accidentally contaminated with PCBs (1000 ppm) and consequently PCDFs (5 ppm). Individuals exhibited a variety of symptoms including fever,	U.S. EPA, 1983 (p. 5-5)

headaches, spasms of hands and feet, skin eruptions and discoloration of skin and mucosa.

3. **Absorption**

Rats receiving a single intraperitoneal injection of a PCDF mixture, exhibited complete hepatic retention of the dosed 2,3,7,8-TCDF component 5 days after the initial administration. — U.S. EPA, 1983 (p. 4-2)

4. **Existing Regulations**

Data not immediately available.

B. Inhalation

Data not immediately available.

III. PLANT EFFECTS

"No data could be found concerning effects of chlorinated dibenzofurans on plants." — U.S. EPA, 1982b (p. 8-1)

IV. DOMESTIC ANIMAL AND WILDLIFE EFFECTS

A. Toxicity

PCDFs have not been studied in model ecosystems and there are very few data available on wildlife. — U.S. EPA, 1982b (p. 5-3)

"While specific causative agents cannot be assigned to effects observed in poisoning incidents, the available data do indicate that adverse effects may be expected to result from exposure of domestic animals to DBFs." — U.S. EPA, 1982b (p. 9-1)

<3% of the PCDFs given in the diet over one year accumulated in tissues of mallards. — Norstrom et al., 1976 (p. 7-1)

See Table 4-1.

B. Uptake

Data not immediately available.

V. AQUATIC LIFE EFFECTS

A. Toxicity

1. Freshwater

a. Acute

Toxicity value for one invertebrate species = 1700 µg/L.	U.S. EPA, 1982b (p. 11-8)

b. Chronic

Data not immediately available.

2. Saltwater

a. Acute

Toxicity value for one species of marine fish = 1800 µg/L.	U.S. EPA, 1982b (p. 11-8)

b. Chronic

Data not immediately available.

B. Uptake

Data not immediately available.

VI. SOIL BIOTA EFFECTS

A. Toxicity

"No data could be found concerning the stability of chlorinated dibenzofurans to microbes, or if chlorinated dibenzofurans exerted toxic effects."	U.S. EPA, 1982b (p. 7-1)
Chlorinated dibenzofurans substituted at the 8-position appear to be bactericidal.	U.S. EPA, 1982b (p. 7-1)

B. Uptake

Data not immediately available.

VII. PHYSICOCHEMICAL DATA FOR ESTIMATING FATE AND TRANSPORT

DBF water solubility: 3 mg/L at 25°C	U.S. EPA, 1982b (Chapter 2)
DBFs quite soluble in organic solvents	
TCDFs melting point: 169 to 228°C	
DBF octanol-water partitioning coefficient: 1,527	
DBF boiling point: 287°C at 760 mm Hg	

TCDFs vapor pressure: (1.8 to 2.5) x 10^{-6} torr
at 25°C (estimated)
DBF specific gravity: 1.0886
Higher DBFs are degraded by light

At present, virtually nothing is known about the dynamics of PCDFs in the environment. U.S. EPA, 1982b (p. 5-1)

TABLE 4-1. TOXICITY OF DIBENZOFURAN TO DOMESTIC ANIMALS AND WILDLIFE

Species (N)[a]	Chemical Form Fed	Feed Concentration (µg/g)	Water Concentration (mg/L)	Daily Intake (mg/kg)	Duration of Study	Effects	References
Guinea Pig	2,3,7,8-TCDF[b]	---	---	0.005-0.010	---	LD_{50}	U.S. EPA, 1982b (p. 12-1)
Mouse/Rat	2,3,7,8-TCDF	---	---	>6	---	LD_{50}	U.S. EPA, 1982b (p. 12-1)
Rhesus Monkey	2,3,7,8-TCDF	---	---	1	---	LD_{50}	U.S. EPA, 1982b (p. 12-1)
Monkey	PCDFs[c]	5	---	---	6 mos.	2 of 3 monkeys died	U.S. EPA, 1982b (p. 12-1)
Chicks	2,3,7,8-TCDF	---	---	0.001	21 days	16 percent mortality	McKinney et al., 1976 (p. 12-23)
Chicks	2,3,7,8-TCDF	---	---	0.005	21 days	100 percent mortality	McKinney et al., 1976 (p. 12-23)
Mouse (10)	PCDFs mixture in gavage	---	---	30.0	30 days	0% mortality	Nishisumi, 1978 (p. 68)
Mouse (10)		---	---	44-67	30 days	10% mortality	
Mouse (10)		---	---	100-150	30 days	30% mortality	
Mouse (10)		---	---	225	30 days	45% mortality	

[a] N = number of experimental animals when reported.
[b] TCDF = Tetrachlorodibenzofuran.
[c] PCDFs = Polychlorinated dibenzofurans.

SECTION 5

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APPENDIX

PRELIMINARY HAZARD INDEX CALCULATIONS FOR TETRACHLORODIBENZOFURANS IN MUNICIPAL SEWAGE SLUDGE

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

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

II. LANDFILLING

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

III. INCINERATION

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

1. **Formula**

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

where:

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

2. **Sample Calculation** - Values were not calculated due to lack of data.

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

1. **Formula**

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

where:

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

2. **Sample Calculation** - Values were not calculated due to lack of data.

IV. OCEAN DISPOSAL

A. Index of Seawater Concentration Resulting from Initial Mixing of Sludge (Index 1)

1. **Formula**

$$\text{Index 1} = \frac{SC \times ST \times PS}{W \times D \times L}$$

where:

SC = Sludge concentration of pollutant (mg/kg DW)
ST = Sludge mass dumped by a single tanker (kg WW)
PS = Percent solids in sludge (kg DW/kg WW)
W = Width of initial plume dilution (m)
D = Depth to pycnocline or effective depth of mixing for shallow water site (m)
L = Length of tanker path (m)

2. **Sample Calculation** - Values were not calculated due to lack of data.

B. Index of Seawater Concentration Representing a 24-Hour Dumping Cycle (Index 2)

1. **Formula**

$$\text{Index 2} = \frac{SS \times SC}{V \times D \times L}$$

where:

SS = Daily sludge disposal rate (kg DW/day)
SC = Sludge concentration of pollutant (mg/kg DW)
V = Average current velocity at site (m/day)
D = Depth to pycnocline or effective depth of mixing for shallow water site (m)
L = Length of tanker path (m)

2. **Sample Calculation** - Values were not calculated due to lack.

C. Index of Toxicity to Aquatic Life (Index 3)

1. **Formula**

$$\text{Index 3} = \frac{I_1}{AWQC}$$

where:

I_1 = Index 1 = Index of seawater concentration resulting from initial mixing after sludge disposal (µg/L)
AWQC = Criterion or other value expressed as an average concentration to protect marine organisms from acute and chronic toxic effects (µg/L)

2. **Sample Calculation** - Values were not calculated due to lack of data.

D. Index of Human Cancer Risk Resulting from Seafood Consumption (Index 4)

1. **Formula**

$$\text{Index 4} = \frac{(I_2 \times BCF \times 10^{-3}\ kg/g \times FS \times QF) + DI}{RSI}$$

where:

I_2 = Index 2 = Index of seawater concentration representing a 24-hour dumping cycle (µg/L)
QF = Dietary consumption of seafood (g WW/day)
FS = Fraction of consumed seafood originating from the disposal site (unitless)
BCF = Bioconcentration factor of pollutant (L/kg)
DI = Average daily human dietary intake of pollutant (µg/day)
RSI = Cancer risk-specific intake (µg/day)

2. **Sample Calculation** - Values were not calculated due to lack of data.