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Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Benzo(a)anthracene

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. Benzo(a)anthracene (BaA) was initially identified as being of potential concern when sludge is landspread (including distribution and marketing), incinerated or ocean disposed.* This profile is a compilation of information that may be useful in determining whether BaA poses 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 → 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, 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 BENZO(A)ANTHRACENE 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 Benzo(a)anthracene

The concentration of BaA is expected to moderately increase above background soil concentrations as a result of landspreading sludge (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.

C. Effect on Plants and Plant Tissue Concentration

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

D. Effect on Herbivorous Animals

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

E. Effect on Humans

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

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

Incineration of sludge may slightly increase BaA concentrations in air above background urban air concentrations; this increase may be substantial when sludge containing a high concentration of BaA is incinerated at a high feed rate (see Index 1). The potential effect of these increased air concentrations of BaA on human cancer risk resulting from inhalation of incinerator emissions could not be determined due to lack of data (see Index 2).

IV. OCEAN DISPOSAL

Slight to moderate increases of the seawater concentration of BaA are evident under all the scenarios evaluated (see Index 1). Slight to moderate increases in the seawater concentration of BaA are apparent over a 24-hour dumping cycle (see Index 2). Only a slight increase of hazard to aquatic life is apparent for all scenarios evaluated (see Index 3). The potential effect of ocean disposal of sludge on human cancer risk resulting from seafood consumption could not be determined due to lack of data (see Index 4).

SECTION 3

PRELIMINARY HAZARD INDICES FOR BENZO(A)ANTHRACENE IN MUNICIPAL SEWAGE SLUDGE

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

A. Effect on Soil Concentration of Benzo(a)anthracene

1. Index of Soil Concentration (Index 1)

a. **Explanation** - Calculates concentrations in µg/g DW of pollutant in sludge-amended soil. Calculated for sludges with typical (median, if available) and worst (95 percentile, if available) pollutant concentrations, respectively, for each of four applications. Loadings (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 preexisting 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 single application as may be used on public lands, reclaimed areas or home gardens.
500 mt/ha	Cumulative loading after 100 years of application at 5 mt/ha/year.

b. **Assumptions/Limitations** - Assumes pollutant is incorporated into the upper 15 cm of soil (i.e., the plow layer), which has an approximate mass (dry matter) of 2×10^3 mt/ha and is then dissipated through first order processes which can be expressed as a soil half-life.

c. **Data Used and Rationale**

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

Typical	0.677 µg/g DW
Worst	4.798 µg/g DW

The typical and worst sludge concentrations are the median and 95th percentile 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) = 0.0054 µg/g DW**

The average of three cultivated soils (<0.001, 0.0072, and 0.0080 µg/g) of BaA was calculated to be 0.0054 µg/g (from values reported by Mathur and Sirois, 1976). (See Section 4, p. 4-1.) These Canadian values are the only BaA values available.

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

Values for the sludge application rate of 500 mt/ha were calculated assuming the degradation rate of BaA to be zero.

d. **Index 1 Values (µg/g DW)**

Sludge Concentration	Sludge Application Rate (mt/ha) 0	5	50	500
Typical	0.0054	0.0071	0.022	0.14
Worst	0.0054	0.017	0.12	0.96

e. **Value Interpretation** - Value equals the expected concentration in sludge-amended soil.

f. **Preliminary Conclusion** - The concentration of BaA is expected to moderately increase above background soil concentrations as a result of landspreading of sludge.

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 soil 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. **Concentration of pollutant in sludge-amended soil (Index 1)**

See Section 3, p. 3-2.

ii. **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. **Concentration of pollutant in sludge-amended soil (Index 1)**

See Section 3, p. 3-2.

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

iii. **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** - Values 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 Phytotoxic Soil Concentration (Index 4)**

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

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. **Concentration of pollutant in sludge-amended soil (Index 1)**

See Section 3, p. 3-2.

ii. **Soil concentration toxic to plants (TP)** - Data not immediately available.

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

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

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

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

a. **Explanation** - Calculates expected tissue concentrations, in μg/g DW, 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 an uptake factor that is constant over all soil concentrations. The uptake factor chosen for the human diet is assumed to be representative of all crops (except fruits) in the human diet. 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. **Concentration of pollutant in sludge-amended soil (Index 1)**

See Section 3, p. 3-2.

ii. **Uptake factor of pollutant in plant tissue (UP)** - Data not immediately available.

d. **Index 5 Values (µg/g DW)** - Values were not calculated due to lack of data.

e. **Value Interpretation** - Value equals the expected concentration in tissues of plants grown in sludge-amended soil. However, any value exceeding the value of Index 6 for the same or a similar plant species may be unrealistically high because it would be precluded by phytoxicity.

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

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

a. **Explanation** - The index value is the maximum tissue concentration, in µg/g DW, associated with phytotoxicity in the same or similar plant species used in Index 5. The purpose is to determine whether the plant tissue concentrations determined in Index 5 for high applications are realistic, or whether such concentrations would be precluded by phytotoxicity. The maximum concentration should be the highest at which some plant growth still occurs (and thus consumption of tissue by animals is possible) but above which consumption by animals is unlikely.

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 phytoxicity (PP)** - Data not immediately available.

d. **Index 6 Values (µg/g DW)** - Values were not calculated due to lack of data.

e. **Value Interpretation** - Value equals the maximum plant tissue concentration which is permitted by phytotoxicity. Value is compared with values for

the same or similar plant species given by Index 5. The lowest of the two indices indicates the maximal increase that can occur at any given application rate.

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

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 feed 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. **Concentration of pollutant in plant grown in sludge-amended soil (Index 5)** - Values were not calculated due to lack of data.

ii. **Feed concentration toxic to herbivorous animal (TA)** - Data not immediately available.

d. **Index 7 Values** - Values were not calculated due to lack of data.

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

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	0.677 µg/g DW
Worst	4.798 µg/g DW

See Section 3, p. 3-1.

ii. **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.

iii. **Feed concentration toxic to herbivorous animal (TA)** - Data not immediately available.

d. **Index 8 Values** - Values were not calculated due to lack of data.

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

E. Effect on Humans

1. Index of Human Cancer Risk 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 the cancer risk-specific intake (RSI) 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. 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. **Concentration of pollutant in plant grown in sludge-amended soil (Index 5)** - Values were not calculated due to lack of data.

ii. **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 (1984b). 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 estimate dry-weight consumption of all non-fruit crops.

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

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

v. **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:

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

d. **Index 9 Values** - Values were not calculated due to lack of data.

e. **Value Interpretaton** - 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 mt/ha indicates the degree to which any hazard is due to sludge application, as opposed to pre-existing dietary sources.

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

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

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

b. **Assumptions/Limitations** - Assumes that all animal products are from animals receiving all their feed from sludge-amended soil. Assumes 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 3 years old.

c. **Data Used and Rationale**

i. **Concentration of pollutant in plant grown in sludge-amended soil (Index 5)** - Values were not calculated due to lack of data.

ii. **Uptake factor of pollutant in animal tissue (UA)** - Data not immediately available.

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

Toddler	43.7 g/day
Adult	88.5 g/day

The fat intake values presented, which comprise meat, fish, poultry, eggs and milk products, are derived from the FDA Revised Total Diet (Pennington, 1983), food groupings listed by the U.S. EPA (1984b) and food composition data given by USDA (1975). Adult intake of meats is based on males 25 to 30 years of age and that for milk products on males 14 to 16 years of age, the age-sex groups with the highest daily intake. Toddler intake of milk products is actually based on infants, since infant milk consumption is the highest among that age group (Pennington, 1983).

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

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

d. **Index 10 Values** - Values were not calculated due to lack of data.

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

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

3. **Index of Human Cancer Risk 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 RSI.

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 3 years old.

c. **Data Used and Rationale**

i. **Animal tissue** - Data not immediately available.

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

Typical	0.677 µg/g DW
Worst	4.798 µg/g DW

See Section 3, p. 3-1.

iii. **Background concentration of pollutant in soil (BS)** = 0.0054 µg/g DW

See Section 3, p. 3-2.

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

See Section 3, p. 3-7.

v. **Uptake factor of pollutant in animal tissue (UA)** - Data not immediately available.

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

Toddler	39.4 g/day
Adult	82.4 g/day

The affected tissue intake value is assumed to be from the fat component of meat only (beef, pork, lamb, veal) and milk products

(Pennington, 1983). This is a slightly more limited choice than for Index 10. Adult intake of meats is based on males 25 to 30 years of age and the intake for milk products on males 14 to 16 years of age, the age-sex groups with the highest daily intake. Toddler intake of milk products is actually based on infants, since infant milk consumption is the highest among that age group (Pennington, 1983).

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

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

d. **Index 11 Values** - Values were not calculated due to lack of data.

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

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

4. **Index of Human Cancer Risk 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 RSI.

b. **Assumptions/Limitations** - Assumes that the pica child consumes an average of 5 g/day of sludge-amended soil. If the RSI specific for a child is not available, this index assumes the RSI 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 RSI provide protection for the child, taking into account the smaller body size and any other differences in sensitivity.

c. **Data Used and Rationale**

i. **Concentration of pollutant in sludge-amended soil (Index 1)**

See Section 3, p. 3-2.

ii. **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, 1984b.

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

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

d. **Index 12 Values** - Values were not calculated due to lack of data.

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

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

5. **Index of Aggregate Human Cancer Risk (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 RSI.

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

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

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

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)**

Typical	0.677 mg/kg DW
Worst	4.798 mg/kg DW

See Section 3, p. 3-1.

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)** = 0.00239 $\mu g/m^3$

The midpoint of BaA concentrations of various U.S. cities (range = 0.00018 to 0.0046 $\mu g/m^3$) was calculated to be 0.00239 $\mu g/m^3$ (U.S. EPA, 1980). (See Section 4, p. 4-2.)

4. **Index 1 Values**

Fraction of Pollutant Emitted Through Stack	Sludge Concentration	Sludge Feed Rate (kg/hr DW)[a] 0	2660	10,000
Typical	Typical	1.0	1.0	1.6
	Worst	1.0	1.3	5.5
Worst	Typical	1.0	1.1	3.5
	Worst	1.0	2.0	19

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

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

6. **Preliminary Conclusion** - Incineration of sludge may slightly increase BaA concentrations in air above background urban air concentrations; this increase may be substantial when sludge containing a high concentration of BaA is incinerated at a high feed rate.

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

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

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

3. **Data Used and Rationale**

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

See Section 3, p. 3-16.

b. **Background concentration of pollutant in urban air (BA)** = 0.00239 $\mu g/m^3$

See Section 3, p. 3-15.

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 x 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)

Typical	0.677 mg/kg DW
Worst	4.798 mg/kg DW

See Section 3, p. 3-1.

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, 1984b).

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, 1984c).

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:

$$W = 40 \text{ m} + 1 \text{ cm/sec} \times 4 \text{ hours} \times 3600 \text{ sec/hour} \times 0.01 \text{ m/cm} = 184 \text{ m} = \text{approximately } 200 \text{ m}$$

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)**

Disposal Conditions and Site Characteristics	Sludge Concentration	Sludge Disposal Rate (mt DW/day) 0	825	1650
Typical	Typical	0.0	0.0014	0.0014
	Worst	0.0	0.0096	0.0096
Worst	Typical	0.0	0.012	0.012
	Worst	0.0	0.082	0.082

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

7. **Preliminary Conclusion** - Slight to moderate increases of the seawater concentration of BaA are evident under all the scenarios evaluated.

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. 3-18 to 3-20.

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

See Section 3, p. 3-21.

5. **Index 2 Values (µg/L)**

Disposal Conditions and Site Characteristics	Sludge Concentration	Sludge Disposal Rate (mt DW/day) 0	825	1650
Typical	Typical	0.0	0.00037	0.00073
	Worst	0.0	0.0026	0.0052
Worst	Typical	0.0	0.0032	0.0064
	Worst	0.0	0.023	0.046

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

7. **Preliminary Conclusion** - Slight to moderate increases in the seawater concentration of BaA are apparent over a 24-hour dumping cycle.

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.

   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)**

   See Section 3, p. 3-21.

   b. **Ambient water quality criterion (AWQC)** = 300 µg/L

   Water quality criteria for the toxic pollutants listed under Section 307(a)(1) of the Clean Water Act of 1977 were developed by the U.S. EPA under Section 304(a)(1) of the Act. These criteria were derived by utilization of data reflecting the resultant environmental impacts and human health effects of these pollutants if present in any body of water. The criteria values presented in this assessment are excerpted from the ambient water quality criteria document for polynuclear aromatic hydrocarbons (PAHs).

   As no BaA-specific values are immediately available, the criterion to protect marine aquatic organisms is based on acute toxicity tests of polychaete worms exposed to crude oil fractions (U.S. EPA, 1980). No chronic toxicity data are presently available for any PAHs. A criterion value based on chronic toxicity data or on more sensitive test organisms would be expected to be lower.

4. **Index 3 Values**

Disposal Conditions and Site Characteristics	Sludge Concentration	Sludge Disposal Rate (mt DW/day) 0	825	1650
Typical	Typical	0.0	0.0000045	0.0000045
	Worst	0.0	0.000032	0.000032
Worst	Typical	0.0	0.000038	0.000038
	Worst	0.0	0.00027	0.00027

5. **Value Interpretation** - Value equals the factor by which the expected seawater concentration increase in BaA exceeds the protective value. A value > 1 indicates that acute or chronic conditions may exist for organisms at the site.

6. **Preliminary Conclusion** - Only a slight increase of hazard to aquatic life is apparent for all scenarios evaluated.

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 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)**

See Section 3, p. 3-22.

Since bioconcentration 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, 1984b). Near-shore area 612 has an area of approximately 4300 km^2 and constitutes approximately 24 percent of the total seafood landings (CDM, 1984c). 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) =** 4620 L/kg

The value chosen is the weighted average BCF of BaA for the edible portion of all freshwater and estuarine aquatic organisms consumed by U.S. citizens (U.S. EPA, 1980). The weighted average BCF is derived as part of the water quality criteria developed by the U.S. EPA to protect human health from the potential carcinogenic effects of BaA induced by ingestion of contaminated water and aquatic organisms. Although no measured steady-state BCF for BaA is available, a BCF for aquatic organisms containing about 7.6% lipids has been estimated from the octanol-water partition coefficient. The weighted average BCF is derived by applying an adjustment factor to the BCF estimate to correct for the 3% lipid content of consumed fish and shellfish. It should be noted, however, that the resulting estimated weighted average BCF of 4620 L/kg represents a worst-case situation. Although data concerning the environmental impacts of PAHs are incomplete, the results of numerous studies show that PAHs demonstrate little tendency for bioaccumulation due to their rapid metabolism. A BCF of 30 obtained from a study of mosquitofish may represent a more realistic value (U.S. EPA, 1980). It should be noted that lipids of marine species differ in both structure and quantity from those of freshwater species. Although a BCF value calculated entirely from marine data would be more appropriate for this assessment, no such data are presently 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:

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

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

5. **Value Interpretation** - Value equals factor by which the expected intake exceeds the RSI. A value >1 indicates a possible human health threat. Comparison with the null index value at 0 mt/day indicates 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 BENZO(A)ANTHRACENE IN MUNICIPAL SEWAGE SLUDGE

I. OCCURRENCE

A. Sludge

1. Frequency of Detection

1,2 BaA detected in 116 out of 437 sludge samples (27%) from 40 POTWs.	U.S. EPA, 1982 (p. 41)

2. Concentration

1,2 BaA detected in 116 out of 437 samples from 40 POTWs at levels ranging from 1 to 1,500 µg/L WW	U.S. EPA, 1982 (p. 41)
1,2 BaA detected in 12 out of 42 sludge samples from 10 POTWs at levels ranging from 200 to 15,000 µg/L WW	U.S. EPA, 1982 (p. 49)
Median = 0.677 µg/g DW 95th percentile = 4.798 µg/g DW	Values statistically derived from sludge concentration data presented in U.S. EPA, 1982

B. Soil - Unpolluted

1. Frequency of Detection

Three cultivated soils and one roadside soil in Ontario, Canada, contained BaA.	Mathur and Sirois, 1976 (p. 265)

2. Concentration

Three cultivated soils in Ontario, Canada, contained <0.001 to 0.0080 µg/g of BaA, and one roadside sample contained 0.0680 µg/g (8.0, 7.2, <1 - cultivated soils, and 68.0 ppb - roadside).	Mathur and Sirois, 1976 (p. 267)
Plants and microorganisms are known to synthesize at least some of the PAHs and may thus contribute to the PAH in soil. Soils may receive PAH from forest fires and from burning of crop residue.	Mathur and Sirois, 1976 (p. 266)

C. **Water - Unpolluted**

1. **Frequency of Detection**

Data not immediately available.

2. **Concentration**

a. **Freshwater**

0.061 μg/L from an unnamed river	Ogan et al., 1979 (p. 1318)

b. **Seawater**

Data not immediately available.

c. **Drinking Water**

0.0033 to <0.0081 μg/L from Ottawa, Canada.	Benoit et al., 1979 (p. 284)

D. **Air**

1. **Frequency of Detection**

Data not immediately available.

2. **Concentration**

BaA in U.S. cities ranges from 0.00018 to 0.0046 $\mu g/m^3$.	U.S. EPA, 1980 (p. C-35)
Combined value for BaA and chrysene in Antwerp, Belgium (residential city area) 0.0022 to 0.013 $\mu g/m^3$	Cautreels and Van Cauwenberghe, 1977 (p. 82)
Combined value for BaA and chrysene in Chacaltaya, Bolivia (remote area), 0.000040 and 0.000065 $\mu g/m^3$	Cautreels and Van Cauwenberghe, 1977 (p. 82)

E. **Food**

1. **Total Average Intake**

Data not immediately available.

2. **Concentration**

BaA concentrations in ppb in a variety of baker's yeast: French - 9.8 to 23.3,	U.S. EPA, 1980 (p. C-29)

German - 2.5 to 15.8, Scottish - 203, and Russian - 10.8

A summary table of BaA concentrations in smoked fish showed values of trace to 0.0017 µg/g. — U.S. EPA, 1980 (p. C-14)

A summary table of BaA concentrations in vegetable oils and margarine showed values ranging from 0.0008 to 0.0295 µg/g. — U.S. EPA, 1980 (p. C-13)

A summary table of BaA concentrations in smoked meats showed values ranging from 0.00004 to 0.029 µg/g. — U.S. EPA, 1980 (p. C-21)

BaA concentrations in ppb in a few vegetable oils and margarine — U.S. EPA, 1980 (p. C-13)

Corn	0.8
Coconut	2.0
Margarine	1.4 to 29.5
Sunflower	13
Soybean	0.9
Olive	1.0
Peanut	1.1

BaA concentrations in ppb in smoked and non-smoked fish — U.S. EPA, 1980 (p. C-14)

Smoked lumpfish	trace
Smoked herring (dried)	1.7
Smoked salmon	0.5
Electric smoked mackerel	1.2
Gas smoked mackerel	0.6
Smoked oysters	19

II. HUMAN EFFECTS

A. Ingestion

1. Carcinogenicity

a. Qualitative Assessment

Increased incidences of lung adenomas and liver hepatomas were observed in mice given BaA by gavage. — Klein, 1963 in U.S. EPA, 1984a (p. 11-16)

b. Potency

Data not immediately available.

c. **Effects**

Lung adenomas and liver hepatomas	Klein, 1963 in U.S. EPA, 1984a (p. 11-16)

2. **Chronic Toxicity**

Data not immediately available.

3. **Absorption Factor**

BaA intestinal transport readily occurs primarily by passive diffusion.	U.S. EPA, 1980 (p. C-37)

4. **Existing Regulations**

A drinking water standard exists for PAHs as a class. The recommended concentration of PAH is not to exceed 0.2 µg/L.	U.S. EPA, 1980 (p. C-108)

B. **Inhalation**

Data not immediately available.

III. PLANT EFFECTS

A. **Phytotoxicity**

Plants are known to synthesize at least some of the PAHs in soil.	Mathur and Sirois, 1976 (p. 266)

B. **Uptake**

PAHs in soils have been shown to be translocated into plants.	Mathur and Sirois, 1976 (p. 266)

See Table 4-1.

IV. DOMESTIC ANIMAL AND WILDLIFE EFFECTS

A. **Toxicity**

1,2 BaA is highly carcinogenic.	Mathur and Sirois, 1976 (p. 265)

See Table 4-2.

B. **Uptake**

Data not immediately available.

V. AQUATIC LIFE EFFECTS

A. **Toxicity**

1. **Freshwater**

Data not immediately available.

2. **Saltwater**

a. **Acute**

Acute toxicity occurred at concentrations as low as 300 µg/L in tests of polychaete worms exposed to crude oil fractions.	U.S. EPA, 1980 (p. B-1, 2)

b. **Chronic**

Data not immediately available.

B. **Uptake**

The estimated weighted average BCF for the edible portion of all freshwater and estaurine aquatic organisms consumed by U.S. citizens is 4,620.	U.S. EPA, 1980 (p. C-17, 19)

VI. SOIL BIOTA EFFECTS

A. **Toxicity**

Microorganisms are known to synthesize at least some of the PAHs in soil.	Mathur and Sirois, 1976 (p. 266)

B. **Uptake**

PAHs in soils can be accumulated, degraded, or both by soil microorganisms.	Mathur and Sirois, 1976 (p. 266)

VII. PHYSICOCHEMICAL DATA FOR ESTIMATING FATE AND TRANSPORT

Molecular weight: 228.28 Melting point: 155 to 157°C Vapor pressure: 5×10^{-9} torr Solubility in water: 0.009 to 0.014 mg/L at 25°C Log octanol/partition coefficient: 5.61	U.S. EPA, 1980 (p. A-4)
BCF values estimated from the equation of Veith et al., 1979	U.S. EPA, 1984a (p. 2)

TABLE 4-1. UPTAKE OF BENZO(A)ANTHRACENE BY PLANTS

Plant/Tissue	Chemical Form Applied	Soil Type	Range of Soil Concentration (μg/g)	Range of Tissue Concentration (μg/g DW)	Uptake Factor[a]	References
Flax/seed	BaA	agricultural	<0.001-0.095	0.0087-0.087	0.91-8.7	Mathur and Sirois, 1976 (p. 269)

[a] Uptake factor = tissue concentration/soil concentration.

TABLE 4-2. TOXICITY OF BENZO(A)ANTHRACENE TO DOMESTIC ANIMALS AND WILDLIFE

Species (N)[a]	Chemical Form Fed	Feed Concentration (µg/g DW)	Water Concentration (mg/L)	Daily Intake (mg/kg)	Duration of Study	Effects	References
Mouse	BaA	NR[b]	30,000	0.5	444 days	Increased incidences of liver and lung tumors	Klein, 1963 in U.S. EPA, 1984a (p. 16)
Mouse	BaA	NR	30,000	0.5	547 days	Increased incidences of liver and lung tumors	Klein, 1963 in U.S. EPA, 1984a (p. 16)

[a] N = Number of test animals.
[b] NR = Not reported.

SECTION 5

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APPENDIX

PRELIMINARY HAZARD INDEX CALCULATIONS FOR BENZO(A)ANTHRACENE IN MUNICIPAL SEWAGE SLUDGE

I. LANDSPREADING AND DISTRIBUTION-AND-MARKETING

A. Effect on Soil Concentration of Benzo(a)anthracene

1. Index of Soil Concentration (Index 1)

a. Formula

$$CS_s = \frac{(SC \times AR) + (BS \times MS)}{AR + MS}$$

$$CS_r = CS_s \left[1 + 0.5^{(1/t_{\frac{1}{2}})} + 0.5^{(2/t_{\frac{1}{2}})} + \ldots + 0.5^{(n/t_{\frac{1}{2}})}\right]$$

where:

- CS_s = Soil concentration of pollutant after a single year's application of sludge (µg/g DW)
- CS_r = Soil concentration of pollutant after the yearly application of sludge has been repeated for n + 1 years (µg/g DW)
- SC = Sludge concentration of pollutant (µg/g DW)
- AR = Sludge application rate (mt/ha)
- MS = 2000 mt ha/DW = assumed mass of soil in upper 15 cm
- BS = Background concentration of pollutant in soil (µg/g DW)
- $t_{\frac{1}{2}}$ = Soil half-life of pollutant (years)
- n = 99 years

b. Sample calculation

CS_s is calculated for AR = 0, 5, and 50 mt/ha (and for AR = 500 mt/ha when $t_{\frac{1}{2}}$ is not available, since CS_r can not be calculated)

$$0.0071\ \mu g/g\ DW = \frac{(0.677\ \mu g/g\ DW \times 5\ mt/ha) + (0.0054\ \mu g/g\ DW \times 2000\ mt/ha)}{(5\ mt/ha\ DW + 2000\ mt/ha\ DW)}$$

B. **Effect on Soil Biota and Predators of Soil Biota**

1. **Index of Soil Biota Toxicity (Index 2)**

a. **Formula**

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

where:

I_1 = Index 1 = Concentration of pollutant in sludge-amended 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**

$$\text{Index 3} = \frac{I_1 \times UB}{TR}$$

where:

I_1 = Index 1 = Concentration of pollutant in sludge-amended soil (µg/g DW)
UB = Uptake factor of pollutant in soil biota (µg/g tissue DW [µg/g soil DW]$^{-1}$)
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 Phytotoxic Soil Concentration (Index 4)**

a. **Formula**

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

where:

I_1 = Index 1 = Concentration of pollutant in sludge-amended soil (µg/g DW)
TP = Soil concentration toxic to plants (µg/g DW)

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

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

a. **Formula**

Index 5 = I_1 x UP

where:

I_1 = Index 1 = Concentration of pollutant in sludge - amended soil (µg/g DW)
UP = Uptake factor of pollutant in plant tissue (µg/g tissue DW [µg/g soil DW]$^{-1}$)

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

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

a. **Formula**

Index 6 = PP

where:

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

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

D. **Effect on Herbivorous Animals**

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

a. **Formula**

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

where:

I_5 = Index 5 = Concentration of pollutant in plant grown in sludge-amended soil (µg/g DW)
TA = Feed concentration toxic to herbivorous animal (µg/g DW)

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

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

a. **Formula**

If AR = 0; Index 8 = 0

$$\text{If AR} \neq 0;\ \text{Index 8} = \frac{SC \times GS}{TA}$$

where:

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

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

E. **Effect on Humans**

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

a. **Formula**

$$\text{Index 9} = \frac{(I_5 \times DT) + DI}{RSI}$$

where:

I_5 = Index 5 = Concentration of pollutant in plant grown in sludge-amended soil (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)
RSI = Cancer risk-specific intake (µg/day)

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

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

a. **Formula**

$$\text{Index 10} = \frac{(I_5 \times UA \times DA) + DI}{RSI}$$

where:

I_5 = Index 5 = Concentration of pollutant in plant grown in sludge-amended soil (µg/g DW)
UA = Uptake factor 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) (milk products and meat, poultry, eggs, fish)
DI = Average daily human dietary intake of pollutant (µg/day)
RSI = Cancer risk-specific intake (µg/day)

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

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

a. **Formula**

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

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

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
UA = Uptake factor 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) (milk products and meat only)
DI = Average daily human dietary intake of pollutant (µg/day)
RSI = Cancer risk-specific intake (µg/day)

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

4. **Index of Human Cancer Risk Resulting from Soil Ingestion (Index 12)**

a. **Formula**

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

where:

I_1 = Index 1 = Concentration of pollutant in sludge-amended soil (µg/g DW)
DS = Assumed amount of soil in human diet (g/day)
DI = Average daily human dietary intake of pollutant (µg/day)
RSI = Cancer risk-specific intake (µg/day)

b. Sample calculation (toddler) - Values were not calculated due to lack of data.

5. Index of Aggregate Human Cancer Risk (Index 13)

a. Formula

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

where:

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

b. Sample calculation (toddler) - Values were not calculated due to lack of data.

II. LANDFILLING

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

III. INCINERATION

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

1. Formula

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

where:

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

2. Sample Calculation

$$1.0 = [(2.78 \times 10^{-7} \text{ hr/sec} \times \text{g/mg} \times 2660 \text{ kg/hr DW} \times 0.677 \text{ mg/kg DW} \times 0.05 \times 3.4\ \mu g/m^3) + 0.00239\ \mu g/m^3] \div 0.00239\ \mu g/m^3$$

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

1. Formula

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

where:

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

2. Sample Calculation - 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

$$0.0014\ \mu g/L = \frac{0.677\ mg/kg\ DW \times 1600000\ kg\ WW \times 0.04\ kg\ DW/kg\ WW \times 10^3 \mu g/mg}{200\ m \times 20\ m \times 8000\ m \times 10^3\ L/m^3}$$

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

$$0.00037\ \mu g/L = \frac{825000\ kg\ DW/day \times 0.677\ mg/kg\ DW \times 10^3\ \mu g/mg}{9500\ m/day \times 20\ m \times 8000\ m \times 10^3\ L/m^3}$$

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**

$$0.0000045 = \frac{0.0014\ \mu g/L}{300\ \mu g/L}$$

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.