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EPA

Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities

DRAFT

DRAFT **Revised April 22, 1994**

Attachment

IMPLEMENTATION GUIDANCE FOR CONDUCTING INDIRECT EXPOSURE ANALYSIS AT RCRA COMBUSTION UNITS

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NOTICE: The recommendations set out in this document are not final Agency action, but are intended solely as guidance. They are not intended, nor can they be relied upon, to create any rights enforceable by any party in litigation with the United States. EPA officials may decide to follow the guidance provided in this memorandum, or to act at variance with the guidance, based on an analysis of specific site circumstances. The Agency also reserves the right to change this guidance.

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1. WHO PERFORMS RISK ASSESSMENTS

With respect to the facility-specific risk assessments, the Draft Waste Minimization and Combustion Strategy (also referred to as Draft Strategy) indicates that risk assessments should be performed prior to permitting, generally by EPA Regions or the authorized State.

Several questions have been raised on whether close Regional or State supervision over facility owners and operators conducting risk assessments could be an acceptable approach. For example, in certain cases, State law requires the owner/operator to conduct the risk assessment. In addition, there may be other cases where the Regions or States believe the facility may be in the best position to conduct the risk assessment. To avoid needless duplication, the Regions and States need not conduct the assessments in those cases but should be intimately involved in the planning and carrying out of the risk assessment and should be formally reviewing and approving the risk assessment protocols.

2. EMISSIONS ISSUES

GUIDANCE ON LEVEL OF ORGANIC COMPOUND IDENTIFICATION REQUIRED FOR RISK ASSESSMENT COMPONENT OF DRAFT STRATEGY

The EPA's Draft Strategy makes a full multiple-route risk assessment a major component in the permitting of boilers and industrial furnaces, and incinerators. To conduct the assessment, EPA will need more extensive analysis of the chemicals identified in the emissions to estimate risks from both direct and indirect exposures. The risk assessment called for in Draft Strategy involves two significant expansions from what was typically conducted previously: (1) the number of routes of exposure will be expanded and (2) the number of compounds analyzed and used in the risk assessment will be expanded in order to identify as large a fraction of the emissions as is realistically possible.

Guidance on Development of Facility-Specific List

While the actual list of compounds the facility must sample and analyze is to be determined by the permit writer, the following guidance is offered to assist the permit writer in developing a site-specific list.

a. The first list the permit writer should consider requiring the facility to sample and analyze is the 12 metals currently regulated under the BIF rule. (For boilers and industrial furnaces, these metals must be addressed; for incinerators, it is strongly recommended they be addressed.) The second list the permit writer should consider requiring the facility to sample and analyze are the compounds recommended in Table 1 of Attachment A (a.k.a. the "PIC list"). The permit writer may also want to include some of the compounds on Table 2 of Attachment A. The compounds on Table 2 are currently being evaluated and may be recommended at a future point in time.

b. Additionally, it is recommended that the permit writer also require the analysis of the 20 largest peaks obtained in the GC-MS analysis of the trial burn. This analysis will help EPA determine whether there are any compounds that are not on the attached PIC list but that are present in high amounts that might significantly affect the risk.

c. The PIC list includes a full substituted dibenzo-p-dioxin and dibenzofuran analysis. It is recommended that the permit writer require the facility to perform this analysis in order to identify compounds with resolution that will identify the number of chlorine (or bromine or other halogens) molecules and whether the congener has a halogen on the 2,3,7,8 positions. The purpose for this resolution is to calculate Toxicity Equivalents (TEQs) which are used to calculate risk at the point of exposure. There are 7 possible 2,3,7,8-substituted dibenzo(p)dioxin congeners, ranging from tetra-substituted to octa-substituted congeners, and 10 possible 2,3,7,8-substituted dibenzofuran congeners, also ranging from tetra-substituted to octa-substituted congeners.

d. The PIC list also includes a full polychlorinated biphenyl (PCB) scan. It is recommended that the permit writer require the facility to perform this analysis in order to determine the total PCB's. There are 209 possible PCB congeners, ranging from mono-substituted congeners to deca-substituted congeners.

e. The permit writer should also require the facility to sample and analyze any additional highly toxic compounds that will be in the trial burn waste in high concentrations. The formulation of the wastes used in the trial burn is intended to provide a representative mixture of constituents that will generate PICs that are characteristic of emissions from the facility in permitted use so that the permit writer can establish protective permit conditions. However, some of these compounds may survive the combustion process and be emitted intact. Hence, the list of principle feed constituents should also be added to the list of compounds for which the facility should sample and analyze. See Attachment B, "Guidance on Trial Burns," for a full discussion of factors to consider in the selection of waste constituents.

f. The permit writer may also require sampling and analysis of nitrogenated organic compounds. At this stage of development of the draft PIC list, not all of these compounds have been added. It is anticipated that EPA's stack sampling program will provide further guidance for nitrogenated PICs that the permit writer may require of the facility. Nitrogenated PICs are expected during the maximum temperature test.

g. The permit writer may also require sampling and analysis of any additional PICs that the permit writer believes are important.

Further guidance on the selection of compounds for analysis is provided in the trial burn guidance (Attachment B).

Development of the PIC List

The draft PIC list (i.e., Attachment A) was developed from existing data in EPA's possession as well as lists of toxic compounds from certain EPA programs. Since these lists were not developed to be lists of toxic PICs, compounds have been deleted from the lists that appear to be inappropriate. EPA recognizes the importance of using specific focused studies to develop a PIC list that is appropriately protective of the environment and not excessively burdensome on the regulated community. However, OSW considers it appropriate to use a draft list that is based on existing data for an interim period. As EPA collects additional PIC data, this list will be revised.

Source lists included:

* The hazardous waste constituent list in 40 CFR 261 Appendix VIII (Office of Solid Waste-OSW)
* The Hazardous Air Pollutants (HAP) list (Office of Air Quality Planning and Standards-OAQPS)

- * Office of Research and Development list of organic compounds found in combustion devices developed for the Draft Addendum to the Indirect Exposure Document (includes PICs found in hazardous waste combustion devices and other combustion devices)

Inappropriate compounds were deleted from this list on the following basis:

- Compound was a pesticide that was unlikely to be a PIC
- Compound listed because it is an FDA regulated drug
- Compound listed because it is a carcinogenic sugar substitute
- Listings that are not chemical specific such as "coal tar"
- Compound for which EPA does not have a sampling and analysis method delineated
- Metallic compounds were deleted because of difficulty in analyzing the specific compounds; metals are still included as elemental totals
- If the compound had a low octanol-water partition coefficient and did not have inhalation toxicity data (i.e., it was not bioaccumulative and there was no direct inhalation toxicity data, thus it would not affect the risk assessment)
- The compound had low toxicity values
- Naturally occurring plant toxins

Certain compounds were kept on the list such as:

- Pesticides that have a molecular structure that is simple enough to be of concern as a PIC
- Compounds with very high octanol- water partition coefficients

Planned Further Development of List

EPA is undertaking experimental studies specifically directed toward determining which toxic organic compounds are likely to be formed in trace quantities from hazardous waste combustion devices. The studies will explore variations in combustion conditions and the effect on the specific organic molecules released. The studies will also focus on defining operating parameters that can affect the type, character, and quantity of PIC emissions.

Accounting for Unidentified Compounds

One of the concerns that has been raised by the public is that, even with the lists described in the previous sections, there may be a significant number of unidentified compounds in the emissions which will contribute to the overall risk from the facility. While the risks associated with heavy metals are believed to be adequately addressed directly, given the recommended level of compound identification, the risks from unidentified organic compounds could potentially be significant. Presented below are two approaches for addressing those potential risks. OSW recommends using the first option but solicits comment on the second approach.

The first option assumes that the unidentified organic compounds are similar in toxicity and chemical properties to those of the identified organic compounds taken as a whole, including compounds from the PIC list and any other voluntarily identified compounds that are toxic or that do not have toxicity data.

Under this assumption, the total risks from the organic compounds would be equal to the risks from the identified organic compounds multiplied by the ratio of the mass of total organic compounds to the mass of the identified organic compounds. This is accomplished computationally by increasing the emission rate of each of the identified organic compounds by the ratio of the concentration of total organic compounds to the concentration of all the identified organic compounds combined. Mathematically, this may be written as follows:

$$Q_{i,adj} = Q_i \cdot \frac{C_{TOC}}{\sum_i C_i}$$

where:

$Q_{i,adj}$ = *adjusted emission rate of compound i*
Q_i = *emission rate of compound i*
C_i = *stack concentration of compound i (carbon basis)*
C_{TOC} = *stack concentration of total organic carbon*

The risk assessment would then be conducted using the adjusted (i.e., increased) emission rates for each of the identified organic compounds. (Note: no adjustment is made to metals emissions.)

The second option would assume that all unidentified organic compounds are carcinogens and have a carcinogenic potency that is similar to the compounds on the PIC list. This option was developed to address the concern that any voluntarily identified compounds, beyond those on the PIC list, would tend to be primarily noncarcinogens or low potency carcinogens.

Under this assumption, the total carcinogenic risk from the organic compounds would be increased by adjusting the emissions of each of the organic carcinogens on the PIC list as follows:

$$Qcp_{i,adj} = Qcp_i \cdot \frac{C_{TOC} - \sum_j Cn_j - \sum_k Ccn_k}{\sum_i Ccp_i}$$

where:

$Qcp_{i,adj}$ = *adjusted emission rate of PIC list carcinogenic compound i*
Qcp_i = *emission rate of PIC list carcinogenic compound i*
Ccp_i = *stack concentration of PIC list carcinogenic compound i (carbon basis)*
Cn_j = *stack concentration of noncarcinogenic compound j (carbon basis)*
Ccn_k = *stack concentration of non-PIC list carcinogenic compound k (carbon basis)*
C_{TOC} = *stack concentration of total organic carbon*

The risk assessment would then proceed using the adjusted (i.e., increased) emissions for the organic carcinogens on the PIC list and the measured (i.e., unadjusted) emissions for the organic carcinogens not on the PIC list and the organic noncarcinogens.

The ratio for adjusting the emissions in the above equations should be based on the mass of carbon. This is because the analytical methods typically used for measuring total organic carbon are based on detection of the amount of carbon dioxide released from thermally oxidizing the sample. The results may be expressed on a carbon atom basis or some other basis (such as propane). Therefore, the measured stack gas concentrations of the organic compounds that are identified in the analysis must all be converted to an equivalent carbon basis, as appropriate.

Total Organic Carbon Analysis

A total organic carbon (TOC) analysis is necessary to account for the portion of the organic emissions that are not specifically identified and quantitated. The permit writer should allow the applicant the latitude to determine the method to be used to measure TOC. At present, EPA cannot recommend a specific method. Discussions with the Office of Research and Development are underway which are intended to lead to the development of a standard method. In the interim, the permit writer should require the applicant to demonstrate that the method being used does detect and measure a variety of organic compound types, such as the types of organic compounds found on the PIC list. The method used should minimize any positive interference from the detection of carbon dioxide and carbon monoxide.

Quality Assurance

In order to encourage as complete an identification of the organic emissions as possible, the permit writer may require less stringent data quality objectives for the organic compounds which are not on the recommended PIC list.

For TOC the permit writer may want to consider establishing specific quality assurance requirements on a case by case basis to ensure the reliability of the data.

Detection Limits

For compounds on the PIC list which are not detected, the permit writer should evaluate whether they are likely to pose a significant risk at concentrations near the detection limit. If this is the case, or if the detection limit achieved during the trial burn is significantly higher than can reasonably be achieved using sound sampling and analysis procedures, then these compounds should be included in the risk assessment at an assumed concentration of 1/2 the detection limit. Other compounds which are not detected need not be considered in the risk assessment.

GUIDANCE ON TRIAL BURNS

See Attachment B.

APPLICATION OF DATA

See Attachment B.

OTHER EMISSION SOURCES

The Draft Strategy is intended to address risks from combustion units burning hazardous wastes. Therefore, the analysis should ideally address air emissions from all sources that are an integral part of the combustion operation, including activities such as storage, blending, and handling of wastes fed to the combustion unit itself, as well as storage and handling of combustion residues (e.g., flyash, bottom ash, and quench water) generated by the combustion facility. For those facilities where these other activities are likely to contribute significant emissions and for which enough information is available to analyze their impact, the following approach is recommended.

"Fugitive" emissions generated from these on-site sources include volatile organics from RCRA-permitted tanks, containers, and related equipment (e.g., pumps, valves, and flanges) used in the storage and handling of liquid hazardous waste and pumpable solids, as well as fugitive dust from storage and handling of combustible solids and combustion residues in open tanks, containers, waste piles, conveyers, and trucks. Fugitive emissions of volatile organics from equipment leaks (pumps, seals, fittings, etc.) can be estimated on the basis of "Protocol for Equipment Leak Emission Estimates", Document No. EPA-453/R-93/026. Fugitive emissions of volatile organics from storage tanks and containers can be estimated using the methodology provided in "Hazardous Waste TSDF: Background Information for Proposed RCRA Air Emission Standards", Document No. EPA-450/3-89-023. These methods have been adapted for spreadsheet calculations in the PC-based model, CHEMDAT7, which is available from the OAQPS Technology Transfer Network (TTN) electronic bulletin board. Fugitive dust emissions from open waste piles and staging areas can be estimated using the methodologies described in "Hazardous Waste TSDF - Fugitive Particulate Matter Air Emissions Guidance Document", Document No. EPA-450/3-89-019. Many of the calculations have been computerized, as described in "User's Manual for the PM-10 Open Fugitive Dust Source Computer Model Package", Document No. EPA-450/3-90-010, and are available from the OAQPS TTN bulletin board. Estimation of fugitive emissions using these methods requires that estimates be made or measurements be taken of the concentration of chemical constituents (e.g., volatile organics, semivolatile organics, and metals) in the wastes being used as feed materials and in the combustion ash residuals.

Emissions from non-RCRA combustion units at the site (e.g., power plants, etc.) and from other RCRA facilities in the geographic area would not be directly included in the analysis but would instead be considered as part of the background levels.

3. RISK CHARACTERIZATION ISSUES

Historically, human health risk assessments in the RCRA program have focussed on high end individual risk or on bounding estimates, such as the hypothetical "most exposed individual" (MEI). In the context of permitting hazardous waste combustion facilities pursuant to the EPA's draft strategy, it is recommended that risk assessors place primary emphasis on characterizing the high end of the range of individual risks. This is because it is anticipated that high end individual risk will weigh heavily in risk management decisions related to permitting.

SCREENING ESTIMATES

As a first step, screening estimates may be used to demonstrate that risk from a particular combustion facility is below a level of concern and that no further risk assessment analysis is needed. Detailed guidance for conducting screening analyses is provided in Attachment C.

The attached guidance, which was developed jointly by OSW and OERR, is meant to serve as a "work book" for permit writers and others to use for performing screening analyses at combustion facilities burning hazardous wastes. The guidance provided in the primary guidance documents (i.e., the 1990 ORD report "Methodology for Assessing Health Risks Associated with Indirect Exposures to Combustor Emissions" and the November 10, 1993 Draft Addendum) has been integrated and simplified for use in the screening procedure. Also, the screening guidance provides recommendations for all parameter values that are required to perform the calculations, except where site-specific values are recommended.

General Approach

The purpose of the screening guidance is to enable permit writers to make conservative yet reasonable estimates of the high-end individual risks from routine facility emissions. The objective is to approximate the high end risk that would be calculated in a site-specific assessment if "high risk" activity patterns occur at the locations of the maximum media concentrations. However, a number of simplifications have been made which in all likelihood will ensure that the screening estimates exceed the corresponding site-specific estimates. (For example, maximum deposition to soils and vegetation are assumed to occur at the same location as the maximum ground-level air concentrations. Also, the algorithms have been simplified by eliminating a number of loss coefficients, many of which would ordinarily have to be calculated; loss coefficients have been retained only where their inclusion is thought to be of particular significance. In addition, for the purpose of modeling atmospheric dispersion and deposition, vapor phase emissions are assumed to disperse and deposit the same as particle phase emissions.)

The screening guidance addresses the major pathways of potential human exposure, both direct and indirect, although the detailed procedures provided in the attached guidance focus on what are generally believed to be the most significant indirect exposures such as ingestion of beef, milk, fish, and vegetables. The screening guidance identifies which indirect exposure pathways are important for what constituents, as determined by the physical and chemical properties of the constituents. The screening guidance recommends that maximum or near maximum estimates of media concentrations be used (i.e., concentrations in air, soils, and surface waters), even if they occur at different locations. The screening guidance recommends that the activity patterns that pose the highest risk (i.e., subsistence farming and fishing) be assumed to occur at the point of maximum concentration, unless site-specific information is available which clearly rules out these activities. In such cases, the guidance recommends that other potentially high risk activity patterns be evaluated at the point of maximum concentration (e.g., eating homegrown vegetables) and that subsistence activities be evaluated at alternative locations where such activities could potentially occur. For each pathway and activity pattern, the screening procedure uses a combination of high end and central tendency values for the remaining parameters (other than media concentrations) to yield reasonable maximum estimates of exposure.

Constituents

For indirect exposures, the screening guidance focuses on a subset of constituents which have been judged to be of the greatest concern by routes of exposure other than direct inhalation alone. A multiple-pathway evaluation which emphasized food chain exposures was conducted for 105 compounds on the PIC list. Factors that were considered in choosing an appropriate subset to address in the indirect exposure screening guidance included the importance of indirect exposure pathways (relative to the direct inhalation pathway) and the relative toxicity of the compound. OSW is currently evaluating the remaining compounds on the PIC list to determine whether additional compounds should be included in the screening guidance.

The subset of constituents that was selected for inclusion in the guidance for assessing indirect exposures is made up of dioxin-like compounds (PCDD's and PCDF's), polycyclic aromatic hydrocarbons (PAH's), polychlorinated biphenyls (PCB's), and metals.[1] Also included are selected chlorophenols, chlorinated benzenes, nitroaromatics, and phthalates. These compounds are among those that are most frequently detected during stack testing of combustion devices.

Other constituents identified in the stack emissions that are present at levels of concern through indirect exposure routes should also be included in the screening analysis. As indicated, OSW is evaluating additional compounds for possible inclusion in the screening guidance. For compounds which are identified in stack gases but are not now addressed in the screening guidance, the Regions may want to contact OSW for assistance in evaluating these compounds and/or obtaining the relevant physical and chemical properties data. Also, as the PIC identification guidance (as discussed in Section 2, Emission Issues) begins to be implemented, the Regions are encouraged to inform OSW of the magnitude and frequency at which the various compounds are being found in stack gases. Such information will enable OSW to evaluate with greater confidence what additional constituents may need to be addressed in future revisions to the guidance.

For direct exposures, the screening analysis should include <u>all constituents</u> for which data are available (i.e., data on emissions and information on toxicologic criteria or benchmarks).

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[1] The April 15, 1994 draft screening guidance, which includes four metals (arsenic, beryllium, lead, and mercury), will be revised to include eight additional metals which are on the PIC list (antimony, barium, cadmium, chromium, nickel, selenium, silver, and thallium).

Given the diverse mixture of constituents to which individuals may be exposed from combustion sources, a screening analysis should consider additivity of both constituents and pathways, as discussed below in the sections "COMBINING CONSTITUENTS" and "COMBINING PATHWAYS" and in the screening guidance. It is important to include the significant constituents and pathways in the screening analysis in order to retain the conservatism necessary for developing appropriate screening estimates.

Although it is anticipated that site-specific land use data will not generally be needed to develop screening estimates, the screening guidance does recommend that some site-specific data be used. This is the case for much of the input data required for the air dispersion and deposition model (currently recommended as COMPDEP), due to the complex interactions among stack related parameters, terrain, and meteorological conditions. Here data availability should not be an issue: values for stack parameters should be available for any facility seeking a RCRA permit; actual terrain data are readily available for virtually all locations; and hourly meteorological data are available for numerous sites around the country. The use of actual terrain and meteorological data is regarded as standard practice for the application of air dispersion models for most air pathway analyses involving the use of long-term (e.g., annual) average ambient air concentrations. Although the effort required to process these data is not trivial, standard procedures and software are available for doing so and are widely used. Sources from which these data may be obtained are identified in the screening guidance.

The screening guidance also recommends that certain site-specific data be used for surface water pathways, in particular the size and location of the watershed or waterbody and, for rivers and streams, the average annual flow. Such data are readily available and should be used; in certain instances, however, conservative default values are provided if needed.

Fugitive Emissions and Upsets

Fugitive emissions and upset emissions should be included in the screening analysis. Although upsets are not generally expected to increase stack emissions by more than a factor of two over the life of the facility, upset emissions should be estimated for the particular facility based on the operating history of the facility or similar facilities. Fugitive emissions should be estimated based on the types of wastes the facility will be burning. (See the discussion of "Other Emission Sources" under Section 2, "Emissions Issues")

Since fugitive emissions have characteristics that are different from those of stack emissions, dispersion of fugitive emissions should be modeled separately, with the plume impacts being added at the receptor point. A number of dispersion models can be used for this purpose, including the FDM and ISC2 models, models which are available on the OAQPS TTN bulletin board.

Ecological Effects

Given the EPA's commitment to the protection of ecosystems, it is also expected that as part of the screening analysis an evaluation should be conducted of the potential for ecological impacts to the extent feasible. (Although this issue arises in both screening and detailed or site-specific assessments, it is discussed here.) The ecological assessment should include identifying critical ecological resources to be protected from reduction, degradation, or loss in quantity, quality or use, including critical fish and wildlife habitat and the presence of endangered species. Also, the ecological assessment should include an evaluation of whether the impacts of the combustion facility on ambient surface water concentrations of toxic constituents are likely to cause exceedances of State water quality standards.

HIGH END INDIVIDUAL EXPOSURE

If the screening analysis indicates that a more detailed, site-specific risk assessment is needed, it should include a description of the high end of the distribution of individual exposure(s).[2] High end exposure(s) are plausible estimates of individual exposure(s) for those persons at the upper end of the distribution. The intent of this descriptor is to convey estimates of exposure in the upper range of the distribution, but to avoid estimates which are beyond or above the true distribution. Conceptually, high end exposure(s) means exposure(s) above the 90th percentile of the population distribution, but not higher than the individual in the population who has the highest exposure.

The Draft Addendum describes an approach for estimating the distribution of exposures across the population in the study area through a combination of concentration isopleths and information on activity patterns (location of farms, residential areas, etc.). This approach provides exposure estimates for population subgroups (farmers, school children, etc.) within each of the isopleths, and these estimates can be combined to yield a general population distribution. The high end individual exposure can then be determined by selecting within the most exposed 10 percent of the distribution.

This approach will require that a substantial amount of information be collected on locations and activity patterns for the whole population of concern in the study area. An alternative approach would be to identify those populations in areas with relatively high concentrations and high risk activity patterns and define these as the high end of the distribution. This alternative

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[2] "Guidance for Risk Assessment", Risk Assessment Council, November 1991.

may require some iterative analysis, particularly since high risk activity patterns can vary depending on the constituent. However, this approach could require collection of substantially less information.

Once a population of concern has been identified, one can either set all exposure parameters such as consumption rates to central tendency values (if this population is relatively small) or else high end exposures within that population can be estimated by identifying the most sensitive parameters that determine the average daily dose and setting the values of one or a few of these to their high end values while leaving all other parameters at their "typical" values.[3] However, combinations of parameter values that are highly unlikely to occur at the same time should be excluded. Generally speaking, parameters that are known to be highly correlated should be varied together. Whether the upper end or the lower end of the distribution of the parameter is used depends on whether the parameter has a directly proportional or inversely proportional relationship to risk. Sensitivity analysis should be performed to support the selection of the most sensitive parameters for the various constituents and pathways.

In setting the values of the most sensitive parameters for use in estimating the high end exposure, it is recommended that values at or above the 90th percentile be used (or, conversely, at or below the 10th percentile). If only a relatively few data points are available, the maximum or near-maximum value should be used (or, conversely, the minimum or near-minimum value).

COMBINING CONSTITUENTS

Generally speaking, the risks to an individual exposed to a mixture of carcinogens should be combined by adding the constituent-specific risks, unless synergistic or antagonistic interactions are known to occur for the specific mixture.[4] However, for systemic toxicants, estimating a hazard index for a mixture is generally appropriate only if the constituents induce the same effect by similar modes of action.[5] Because different effects occur for the same chemical at different dosages, and because biochemical mechanisms are infrequently known or understood, it is suggested that hazard indices for mixtures be estimated only if, at a minimum, the RfDs of the individual

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[3] Ibid.

[4] "The Risk Assessment Guidelines of 1986", Office of Health and Environmental Assessment, August 1987.

[5] Ibid.

components are all based on effects in the same target organ.[6] It should be noted that, since many carcinogens also exhibit systemic effects, carcinogens should be included for consideration when non-cancer individual risks from chemical mixtures are being evaluated.[7]

COMBINING PATHWAYS

When estimating individual daily doses, exposures from different pathways should be added for each route of exposure (i.e., oral, dermal, or inhalation) if there is a reasonable expectation that the same individuals are exposed.

For carcinogens, exposures can be added across direct and indirect pathways if the constituent is a carcinogen through both oral and inhalation routes. For non-carcinogens, it is appropriate to add oral and inhalation exposures only if there is information to indicate that the oral reference dose and the inhalation reference concentration are based on the same effect. Generally, dermal exposures can be combined with oral exposures.

When combining exposures, it is important to consider whether the same individual is likely to be exposed through each of the exposure pathways that are being added.

EXPOSURE DURATION

The duration of exposure should take into account both the expected operational life of the facility and the time period of residence that is discussed in the guidance. For many exposure pathways, exposures may continue after the facility has ceased operations, due to continued cycling of contamination in and between biota, soils, and sediments. Generally speaking, exposure durations should represent less-than-lifetime exposures, unless it is reasonable to expect that individuals will be exposed for a lifetime. Estimates of the likely duration of exposure via a given exposure pathway should be made wherever possible. Local census data and, for unusual situations, limited site-specific surveys can help establish the likely durations of individual exposures.

4. RISK MANAGEMENT ISSUES

LAND USE

The risk assessment should consider both current land use and ways in which the land surrounding a combustion unit are reasonably

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[6] "Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual (Part A)", Office of Emergency and Remedial Response, December 1989.

[7] Ibid.

likely to be used so that the appropriate exposure pathways, potentially exposed populations, exposure parameters, and equations can be used to estimate acceptable emission limitations. To determine reasonably expected land uses, risk assessors should rely on a combination of available information and best professional judgment. Several factors to be considered for determining reasonably expected land use include: projected land use based on recent trends, changes in population growth and population density near the combustion unit, and restricted land uses because of local zoning laws.

ACCEPTABLE TARGET LEVEL

To ensure protection of human health from emissions of toxic constituents, the total incremental risk from the high-end individual exposure to carcinogenic constituents should not exceed 10^{-5}. For systemic toxicants, the hazard quotient (e.g., the ratio of the total daily oral intake to the reference dose) for the constituent or, when appropriate, the mixture should be less than 0.25.[8] In the case of lead, for which there is no reference dose, direct comparison with media-specific health based levels is suggested, after adjusting for background levels; specifically, values of 100 mg/kg for soils and 0.2 $\mu g/m^3$ for air are recommended. (Note: See the discussions on "COMBINING CONSTITUENTS" and "COMBINING PATHWAYS" for more specific guidance.)

The selection of these levels (as opposed to, for example, an incremental cancer risk level of 10^{-4} and a hazard quotient of 1.0) was done in part to account for exposure to background levels of contamination (including indirect exposures from other combustion units) which should be considered as part of the risk estimation and decision-making process to set emission levels at a combustion unit. The unit will not likely be the only source contributing to exposures in the study area and to neglect other environmental sources may overestimate an allowable emission level, leading to unacceptable total risk to the public. In this case, background is defined as those exposures in drinking water, food, and air attributable to sources other than the combustion unit(s) being assessed.

If detailed information on background sources is available for a particular area, the permit writer may choose to use this information to develop an alternative approach for incorporating background levels.

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[8] This approach is consistent with the approach taken in the Boiler and Industrial Furnace Rule, 56 FR 7169 (February 21, 1991). However, the way in which cancer risk is estimated in this guidance differs from the BIF rule to more closely follow Agency guidance. For example, in the BIF rule carcinogenic metals and organic compounds are not aggregated, Group A and B carcinogens are not aggregated with Group C carcinogens, and a hypothetical MEI is estimated.

NOTE: The results of any risk assessment which is conducted pursuant to this guidance do not replace the requirements of the BIF rules at 40 CFR Part 266 Subpart H. Therefore, allowable levels of metals emissions that are derived from a risk assessment conducted pursuant to this guidance should be compared to those determined under the BIF rule and the more stringent levels should be used to establish the permit limits. However, for incinerators, allowable levels that are derived from a risk assessment conducted pursuant to this guidance should be used to establish the permit limits, as applied under Omnibus authority.

Attachment A

Table 1. Chemicals Recommended for Identification

CAS Number	Chemical Name
75-07-0	Acetaldehyde
98-86-2	Acetophenone
107-02-8	Acrolein
107-13-1	Acrylonitrile
	Anthracene
7440-36-0	Antimony
7440-38-2	Arsenic
7440-39-3	Barium
	Benzaldehyde
71-43-2	Benzene
56-55-3	Benzo(a)anthracene
205-99-2	Benzo(b)fluoranthene
	Benzo(j)fluoranthene
	Benzo(k)fluoranthene
50-32-8	Benzo(a)pyrene
	Benzo(e)pyrene
	Benzo(g,h)perylene
96-07-7	Benzotrichloride
100-44-7	Benzyl chloride
7440-41-7	Beryllium
92-52-4	Biphenyl
111-91-1	Bis(2-chloroethoxy)methane
117-81-7	Bis(2-ethylhexyl)phthalate
	Bromochloromethane
	Bromodichloromethane
590-60-2	Bromoethene

Table 1. Chemicals Recommended for Identification

CAS Number	Chemical Name
75-25-2	Bromoform
74-83-9	Bromomethane
106-99-0	1,3-Butadiene
85-66-7	Butylbenzyl phthalate
7440-43-9	Cadmium
56-23-5	Carbon tetrachloride
57-74-9	Chlordane
532-27-4	2-Chloroacetophenone
106-47-8	p-Chloroaniline
106-90-7	Chlorobenzene
510-15-6	Chlorobenzilate
67-66-3	Chloroform
74-87-3	Chloromethane
91-58-7	ß-Chloronaphthalene
95-57-8	2-Chlorophenol
75-29-6	2-Chloropropane
7440-47-3	Chromium
218-01-9	Chrysene
1319-77-3	m-Cresol
1319-77-3	o-Cresol
1319-77-3	p-Cresol
4170-30-3	Crotonaldehyde
94-75-7	2,4-D
3547-04-4	DDE
53-70-3	Dibenz(a,h)anthracene
96-12-8	1,2-Dibromo-3-chloropropane
84-74-2	Dibutyl phthalate
95-50-1	1,3-Dichlorobenzene

Table 1. Chemicals Recommended for Identification

CAS Number	Chemical Name
95-50-1	1,2-Dichlorobenzene
106-46-7	1,4-Dichlorobenzene
764-41-0	(cis)1,4-Dichloro-2-butene
764-41-0	(trans)1,4-Dichloro-2-butene
75-71-8	Dichlorodifluoromethane
107-06-2	1,2-Dichloroethane
75-35-4	1,1-Dichloroethylene
156-80-5	(trans)1,2-dichloroethylene
120-83-2	2,4-Dichlorophenol
542-75-6	(cis)1,3-Dichloropropene
542-75-6	(trans)1,3-Dichloropropene
84-66-2	Diethyl phthalate
105-67-9	2,4-Dimethylphenol
131-11-3	Dimethyl phthalate
119-90-4	3,3′-Dimethoxybenzidine
99-65-0	1,3-Dinitrobenzene
	o-Dinitrobenzene
100-29-4	p-Dinitrobenzene
121-14-2	2,4-Dinitrotoluene
606-20-2	2,6-Dinitrotoluene
117-84-0	Di(n)octyl phthlate
123-39-1	1,4-Dioxane
100-41-4	Ethylbenzene
106-93-4	Ethylene dibromide
75-21-8	Ethylene oxide
96-45-7	Ethylene thiourea
75-34-3	Ethylidene dichloride
206-44-0	Fluoranthene

Table 1. Chemicals Recommended for Identification

CAS Number	Chemical Name
50-00-0	Formaldehyde
	1,2,3,4,6,7,8-Heptachlorodibenzo(p)dioxin
	1,2,3,4,6,7,8-Heptachlorodibenzofuran
	1,2,3,4,7,8,9-Heptachlorodibenzofuran
76-44-8	Heptachlor
	1,2,3,4,7,8-Hexachlorodibenzo(p)dioxin
	1,2,3,6,7,8-Hexachlorodibenzo(p)dioxin
	1,2,3,7,8,9-Hexachlorodibenzo(p)dioxin
	1,2,3,4,7,8-Hexachorodibenzofuran
	1,2,3,6,7,8-Hexachlorodibenzofuran
	1,2,3,7,8,9-Hexachlorodibenzofuran
	2,3,4,6,7,8-Hexachlorodibenzofuran
118-74-1	Hexachlorobenzene
87-68-3	Hexachlorobutadiene
319-84-6	α-Hexachlorocyclohexane
319-85-7	ß-Hexachlorocyclohexane
	τ-Hexachlorocyclohexane
77-47-4	Hexachlorocyclopentadiene
67-72-1	Hexachloroethane
70-30-4	Hexachlorophene
110-54-3	n-Hexane
193-39-5	Indeno(1,2,3-cd)pyrene
7439-2-1	Lead
123-33-1	Maleic hydrazide
7440-97-6	Mercury
72-43-5	Methoxychlor
71-55-6	Methyl chloroform
106-87-2	Methylcyclohexane

Table 1. Chemicals Recommended for Identification

CAS Number	Chemical Name
78-93-3	Methyl ethyl ketone
74-95-3	Methylene bromide
75-09-2	Methylene chloride
91-20-3	Naphthalene
	Nickel
88-74-4	o-Nitroaniline
96-95-3	Nitrobenzene
100-02-7	4-Nitrophenol
924-16-3	N-Nitroso di-n-butylamine
	Octachlorodibenzo(p)dioxin
	Octachlorodibenzofuran
	1,2,3,7,8-Pentachlorodibenzo(p)dioxin
	1,2,3,7,8-Pentachlorodibenzofuran
	2,3,4,7,8-Pentachlorodibenzofuran
608-93-5	Pentachlorobenzene
82-68-8	Pentachloronitrobenzene
87-86-5	Pentachlorophenol
108-95-2	Phenol
75-44-5	Phosgene
1336-36-3	Polychlorinated biphenyls (209 congeners)
123-36-6	Propionaldehyde
78-87-5	Propylene dichloride
91-22-5	Quinoline
106-51-4	Quinone
94-59-7	Safrole (5-(2-Propenyl)-1,3-benzodioxole)
	Selenium
7440-22-4	Silver
100-42-5	Styrene

Table 1. Chemicals Recommended for Identification

CAS Number	Chemical Name
95-94-3	1,2,4,5-Tetrachlorobenzene
	2,3,7,8-Tetrachlorodibenzo(p)dioxin
1746-01-6	2,3,7,8-Tetrachlorodibenzofuran
630-20-6	1,1,1,2-Tetrachloroethane
79-34-5	1,1,2,2-Tetrachloroethane
127-18-4	Tetrachloroethylene
58-90-21	2,3,4,6-Tetrachlorophenol
7440-28-0	Thallium
106-88-3	Toluene
95-53-4	o-Toluidine
106-49-0	p-Toluidine
120-82-1	1,2,4-Trichlorobenzene
79-00-5	1,1,2-Trichloroethane
79-01-6	Trichloroethylene
75-69-4	Trichlorofluoromethane
95-95-4	2,4,5-Trichlorophenol
88-06-2	2,4,6-Trichlorophenol
96-18-4	1,2,3-Trichloropropane
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane
108-05-4	Vinyl acetate
75-01-4	Vinyl chloride
75-35-4	Vinylidine chloride
1330-20-7	m-Dimethyl benzene (xylene)
1330-20-7	o-Dimethyl benzene (xylene)
1330-20-7	p-Dimethyl benzene (xylene)

Table 2. Chemicals for Potential Identification

CAS Number	Chemical Name
	Ammonia
	Aniline
	o-Anisidine
	Azobenzene
	Bis (2-chloroethyl) ether
	Bis (chloromethyl) ether
	Carbon disulfide
	Chlorocyclopentadiene
	Cumene
	Cyanogen
	Cyanogen bromide
	Cyanogen chloride
	2-Cyclohexyl-4,6-dinitropenol
	Dibenzo(a,e)fluoranthene
	Dibenzo(a,h)flouranthene
	3,3-Dichlorobenzidine
	Dichloroisopropyl ether
	Dichloromethyl ether
	Dichloropentadiene
	Dimethyl aminoazobenzene
	1,2-Dimethylhydrazine
	Dimethylnitrosamine
	Dimethyl sulfate
	4,6-Dinitro-o-cresol
	2,4-Dinitrophenol
	Diphenylamine
	1,2-Diphenylhydrazine
	Di-n-propylnitrosamine

Table 2. Chemicals for Potential Identification

CAS Number	Chemical Name
	Endothall
	Epichlorohydrin
	2-Ethoxyethanol
	Ethyl carbamate
	Ethyl chloride
	Ethyl methacrylate
	Ethyl methanesulfonate
	Ethylene glycol
	Ethylene glycol monobutyl ether
	Ethylene glycol monethyl ether
	Ethylene glycol monoethyl ether acetate
	Formic acid
	Furfural
	Glycidylaaldehyde
	Hexamethylene-1,5-diisocyanate
	Malononitrile
	Methacrylonitrile
	2-Methoxyethanol
	Methyl isobutyl ketone
	Methyl isocyanate
	Methyl mercury
	Methyl styrene (mixed isomers)
	Methyl tert-butyl ether
	4,4-Methylenedianiline
	Phthalic anhydride
	Pronamide
	1,3-Propane sultone
	Propargyl alcohol

Table 2. Chemicals for Potential Identification

CAS Number	Chemical Name
	Propylene glycol monomethyl ether
	Pyridine
	Strychnine
	Toluene-2,6-diamine
	2,4-Toluene diisocyante
	2,2,4-Trimethylpentane
	1,3,5-Trinitrobenzene

Attachment B

GUIDANCE ON TRIAL BURNS

Historically, RCRA trial burns have been conducted in order for hazardous waste combustion facilities to demonstrate compliance with regulatory performance standards and other emission limits. Applicable emission standards included minimum destruction and removal efficiency (DRE) for selected principal organic hazardous constituents (POHCs), as well as risk-based mass emission limits for toxic metals. Since it is not possible to conduct stack emissions monitoring for specific organic and metal constituents on a continuous basis, the conditions at which the combustion device operated during the trial burn were included in the permit as conditions for operation.

Implementation of the Draft Waste Minimization and Combustion Strategy (hereafter referred to as the Draft Strategy) expands the objective and use of data generated from trial burns. Under the Draft Strategy, comprehensive emissions data must be generated during the trial burn for incorporation into multi-end point risk assessments.

The principal new trial burn information which must be generated to support multi-endpoint risk assessments is stack emissions data on a much wider range of organic constituents. These organic constituents are loosely referred to as products of incomplete combustion (PICs). There is concern that PIC emissions, including dioxin/furan compounds, <u>may</u> significantly contribute to the overall risk posed by hazardous waste combustion facilities. In general, the available information database is limited relative to the waste composition and unit operating conditions on PIC speciation and concentration. Prior evaluations have suggested that limiting stack carbon monoxide to 100 ppmv (corrected to 7% oxygen) and/or hydrocarbon (HC) concentration to less than 20 ppmv (as propane, measured hot, corrected to 7% oxygen) will adequately control the inhalation risk from PICs. However, with respect to risk from indirect exposure, there is not sufficient information currently available to verify that the CO and HC emission limits (as identified above) are sufficiently protective. Consequently, it will be necessary to further speciate PICs and quantify individual PIC emission rates as part of the trial burn process at each facility.

Metals emissions data is another important consideration. Metals emissions determinations should be expanded to generate data on metals which can be important for multi-pathway risk assessments (i.e., copper, aluminum, nickel, selenium, and zinc[1]) in addition to the ten toxic metals identified in the boiler/industrial furnace regulation which are of concern from the inhalation pathway. Metals speciation information is also desirable for risk assessments. Stack test data typically provides information on the total mass emission rate of a particular metal, but not on the chemical speciation of that metal. Unfortunately, for the majority of metals, this issue cannot be addressed at this time since, with a few exceptions, analytical methods to accomplish metals speciation are not yet available. As analytical methods become available, permit writers may consider adding metals speciation determinations to trial burns.

The current "Guidance on Setting Permit Conditions and Reporting Trial Burn Results" addresses trial burn planning for determining compliance with DRE and other regulatory performance standards. Similarly, the boiler/industrial furnace regulations and accompanying guidance provide trial burn planning guidelines for determining compliance with risk-based metals emissions limits. Therefore, this guidance is intended as a supplement to the previous guidance to more specifically address generation of organic PIC emissions data during trial burns for use in multi-end point risk assessments.

TRIAL BURN CONDITIONS NEEDED TO GENERATE PIC EMISSIONS DATA FOR USE IN RISK ASSESSMENTS

A brief review of definitions and current guidance is appropriate in order to provide a framework for the topics contained in this guidance. First, there has been historic confusion relative to the terms POHCs, PICs, and organics. For the current guidance, use of the term "PIC" encompasses any organic species emitted from the stack, regardless of the origin of the compound. Risk assessments are generally concerned with the health risks posed by emissions from the facility. It makes no difference with respect to risk if the organic was formed from a compound specified as a POHC, if it is a partial oxidation product of the POHC, or if it formed from other materials added to the combustion device. However, from a trial burn perspective, it may be beneficial for the permit writer to consider three sub-categories of the broad grouping of PICs. These include:

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[1] Some of these metals, such as copper and aluminum, may not have a significant impact directly on the risk assessment, but may affect the formation of other toxic compounds such as dioxins/furans.

- Unburned organics originally present in the waste feed, but not necessarily selected as "POHCs" for determination of DRE.

- Other PICs (i.e., from partial destruction and/or recombination reactions), and

- Other trace toxic organics such as dioxins and furans that may be formed downstream of the combustion chamber by low temperature reactions involving fly ash.

The first of these three groups is included since failure to destroy any organic included in the waste feed can contribute to the overall risk posed by the facility. The second group includes the wide range of compounds that are traditionally thought of as PICs. The final group, which includes dioxins and furans, is actually a sub group of the earlier categories but has been singled out because these compounds are expected to have a profound influence on risk assessment. They are also singled out because they are formed under conditions that must be specifically considered in planning trial burns.

Also, a brief review of current trial burn planning guidance is helpful. As mentioned previously, trial burn operating conditions have historically played an important role in assuring ongoing performance with DRE and metals performance standards. Key "control parameters" were identified before the trial burn. As part of the trial burn planning process, waste feed and combustion device operating conditions were selected in order to determine the operating extremities for each of the control parameters (i.e., maximum chloride feed rate, minimum temperature, etc.). Permit limits were placed on each of the control parameters based on measurements taken during the trial burn. These "permitted operating limits" defined the range of acceptable operation for post-trial burn operation. As long as the combustion device was operated within the permitted range, it was assumed to be meeting the emissions performance standards.

In order to implement the Draft Strategy, the data needs for the risk assessment must also be addressed as part of trial burn planning. From a risk assessment standpoint, there is support for measuring PIC emissions during <u>normal</u> operation of the combustion device (instead of the extreme ranges which have been required during DRE and metals tests). The emissions during normal operation may relate more directly to the risk posed by the combustion device over its operating life. However, we are not aware of any mechanism to set permit conditions to assure that the average emissions posed by the "normal" operation, tested during the trial burn, will not be exceeded. Nor is it possible to continuously monitor the emissions of toxic pollutants used in the risk assessment. Therefore, this guidance generally recommends that emissions data for use in the risk assessment be generated based on the "permitted operating limits" developed during the trial burn for PICs, similar to the approach that has been historically used for DRE and metals trial burns.

One challenge relative to the "permitted operating limits" PIC condition approach is that there is limited information available on how waste feed and unit operations impact speciation and concentration of the wide range of PICs that must be accounted for in the risk assessments. Traditionally, trial burns have included special tests for: (1) metals where the system operating temperature is maximized; and (2) for POHC emissions, where system temperatures are minimized. There is a logical argument which suggests that the trial burn conditions for POHC emissions will also result in significant PIC emissions, particularly if PICs are specifically considered in selecting trial burn feeds. However, available data does not show that this argument is necessarily valid for dioxins and furans, which are critically important PICs. For dioxins and furans, catalytic formation seems to be more dependent on the higher air pollution control device temperatures that are typically seen during a worst-case metals test. Therefore, to reflect the range of operating conditions that could influence PIC emissions, this guidance recommends that PIC emissions be quantified during both the minimum temperature POHC test(s) and the maximum temperature metals test(s). In planning these tests, consideration must be given to the additional control parameters identified in this guidance which could potentially influence PIC generation.

Characteristics of the waste burned, the combustion technology employed, and the flue gas cleaning equipment used are all expected to influence the types and amount of PICs generated and emitted. At this time, the major items of concern with respect to worst-case PIC generation conditions during trial burns are listed following this section. For each item, general recommendations are provided regarding whether the specific parameter is best demonstrated during the low temperature POHC test(s) or the high temperature metals test(s). In addition, the guidance suggests which parameters should be specifically translated into final permit conditions.

As a cautionary note, the permit writer must keep in mind that the owner/operator of the facility will generally attempt to get the device permitted for the broadest band of operating conditions (i.e., the most extreme operating conditions). Therefore, the permit writer must take great care in reviewing the trial burn to assure that he/she will be able to set appropriate performance (permit) standards based on the trial burn, and, that the trial burn itself does not pose an imminent hazard to human health or the environment (as specified in Subpart 260.62 of 40CFR). In addition, he should be reasonably confident that the trial burn will not result in the violation of applicable standards such as DRE and CO.

To assure that there is no problems during the trial burn the permit writer must have some assurance that the device is operated under Good Operating Conditions (GOC). Due to the complexity and number of different types of devices involved this document does not attempt to fully define GOC. However, the permit writer should use his experience and engineering judgement in making the determination as well as documents such as the draft "Combustion Emissions Technical Resource Document" (CETRED). CETRED defines Best Operating Practices (BOP) for some devices. The permit writer may endeavor (and is encouraged) to implement BOP as defined in CETRED, if applicable, even if he/she is able to determine GOC by other means. If the permit writer is left with a particularly difficult determination, he/she should feel free to call on the resources of the Waste Combustion Permit Writers' Work Group.

WASTE FEED CONDITIONS

Test data from hazardous waste and other combustion processes show many of the same PICs are formed regardless of the type of waste or fuel burned. In other instances, PIC characteristics may be directly related to the waste chemical composition or physical properties. To best reflect PICs which might be directly related to site-specific waste composition, trial burns should utilize reasonable worst-case "real" wastes (which may be spiked with POHCs or other constituents) instead of surrogate wastes (wastes synthesized from mixtures of pure compounds). Representative wastes should be selected based upon a review of the wastes handled at the particular facility. This issue is discussed in more detail under SELECTION OF REAL WASTES BASED ON QUANTITY AND TOXICITY. Considering site-to-site variations in both the waste composition and technologies employed, realistic conditions to demonstrate maximum PIC emissions must be selected with an understanding of factors which influence the formation and emission control of PICs.

Major PICs of concern include chlorinated (or brominated) compounds such as dibenzo-p-dioxins, chlorinated dibenzofurans, chlorobenzenes, chlorophenols, polychlorinated biphenyls (PCBs); polycyclic aromatic hydrocarbons (PAHs); and nitrogenated PAHs.

PIC formation may result from poor combustion conditions in the high temperature regions of the combustor. PICs may also be formed (or transformed) through low temperature reactions in system components downstream of the combustor. Poor combustion can result from a variety of factors including uneven feed conditions, inadequate combustion temperatures or residence times, low or excessive amounts of combustion air, and inadequate mixing. In the case of highly chlorinated wastes, PIC formation can also result from chlorine or other halogen combustion reactions which reduce the amount of OH radicals necessary for complete destruction of hydrocarbons[2].

Low temperature PIC formation and transformation downstream of the combustor is extremely important from a risk assessment perspective. Data from municipal waste combustion systems, medical waste incinerators, and cement kilns indicate that the majority of dioxins and furans emitted from these facilities are generally created in the low temperature regions provided by particulate control devices. This low temperature formation of dioxin and related chloro-organic compounds (and possibly bromo-organic compounds) involve fly ash catalyzed reactions of halogens with undestroyed organic material from the furnace[3]. In some cases, some organics in the stack gases may originate in raw materials other than the hazardous waste which are fed to the furnace. Metals which are thought to promote these reactions include copper, iron, zinc, nickel, and aluminum. The source of organic material for these low temperature reactions can either be from (1) specific precursor compounds (chlorobenzenes, chlorophenols, etc.,) which escape destruction in the high temperature regions of the combustor or (2) organic decomposition products originating from low temperature oxidization of the carbon in fly ash. The rate of PIC formation is dependent upon the amount of undestroyed organics, the amount and form of halogens (amount of dioxin precursors present), the amount and composition of fly ash, the flue gas composition, and the APCD temperature. Under some conditions, large amounts of chlorinated organics can be created in particulate matter collection devices.

The following list of waste/feed extremities should be considered in the development of the trial burn plan. The extremities in this discussion refer to the maximum or minimum trial burn condition or potential permit condition, as applicable. Although they are referred to as extremities, they should always represent good operating practice:

1. <u>Variability of Batched-Charged Waste Feed</u> Higher levels of PICs are produced during combustion upsets. Upset conditions may result from short term variations (i.e., less than 15 minutes) in the properties of fuel or waste being fed to the combustor. As noted earlier, trial burn tests for collecting PIC risk assessment data should be conducted while the unit is

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[2] Wesbrook, C.K., Inhibition of Hydrogen Oxidation in Laminar Flames and Detonations by Halogenated Compounds, Nineteenth Symposium (International) on Combustion, The Combustion Institute, 1982, (pp.127-141).

[3] In some cases, the organics in the stack gases may originate in the raw materials fed to the furnace, especially in the case of a cement kiln.

burning waste that is representative of the wastes normally burned at the facility. This guidance is particularly important for commercial burners where the waste is received from many sources and the feed is reasonably expected to be highly variable. In these situations, there is concern that rapid changes in waste characteristics may disrupt the normal sequence of oxidation reactions, such as with "puffing", and lead to significant PIC release. Phenomena of this type may not be revealed through testing unless the tests are carefully planned to assure the material burned adequately characterizes the reasonable worst case waste that could create such a phenomenon.

It is suggested that the permit writer carefully examine the expected characteristics of waste to be burned at a facility and assure the applicant develops a trial burn in which the unit is fired with a sequence of waste that is representative of wastes typically burned at the facility. If the unit is batch charged (such as drum fed rotary kilns), individual charges should present the incinerator with the most challenge with respect to parameters such as waste volatility, waste heating value, moisture content, molecular weight, oxygen content, and halogen content that are expected to be fed to the incinerator. Once these parameters are maximized (or minimized as in the case of O_2 content), variations between the charges and their sequencing should be minimized to increase the repeatability of the test runs. This scenario is consistent with the "Guidance on Setting Permit Conditions and Reporting Trial Burn Results" which specifies the feeding of containers with the highest volatility during the trial burn. The high moisture content requirement may be in conflict with some of the other parameters such as volatility and heating value. Therefore, if the moisture content is higher than a nominal amount in containers (approximately 5%), then the facility should consider another test run with maximized moisture content.

If the trial burn waste or fuel is oxygenated, this oxygen level should be considered as a floor when setting permit conditions. Ideally, the incinerator and its control system will be designed and operated to account for this type of variability. If not, the shortcoming will probably be reflected in higher PIC emissions and higher indicated unit risks. These higher PIC emissions will be reflected in higher CO and HC measurements as well as low O_2. If this situation is a problem the facility must find ways to reduce the waste variability to minimize emissions and upsets. In some cases, a new test may be required or the permit writer may consider other measures such as minimum excess oxygen levels.

Permit limits should address the same parameters as other wastes as well batch size, frequency, heating value, and container type (including thickness).

2. Wastes with a high content of halogens. A high halogen content may locally deplete the available OH radicals which are necessary for complete destruction of organics and may lead to excessive amounts of PAHs or halogenated organics being formed. Generally, these halogenated organics, which include dioxins and furans, are the most toxic PICs. While this problem may be associated with all types of combustors, liquid waste incinerators operating with high halogen feed concentrations and relatively low excess air levels may be particularly vulnerable. Therefore, testing should be conducted using the highest levels of halogens in the wastes and auxiliary fuels which will be allowed by the permit.

The "high halogen waste feed" parameter should ideally be demonstrated during both the minimum combustion temperature POHC test and the maximum combustion temperature metals test. By demonstrating this parameter during the minimum temperature test, the combined impact of high halogen concentration and low temperature on incomplete destruction (and resulting PIC emissions) can be characterized. The high halogen concentration is also important during the high temperature metals test to characterize the impact of chlorinated precursor compounds from the furnace combined with downstream catalytic formation in the air pollution control device, particularly for dioxin/furan compounds. This recommendation assumes that the air pollution control device inlet temperature will be higher during the metals test than the POHC test (although this assumption would have to be verified on a site-specific basis). Existing data shows that higher temperatures in dry air pollution control devices result in higher levels of catalytically-formed dioxins and furans.

In addition to the impact of high halogen concentrations on downstream PIC formation, high chloride inputs are required during metals tests because chlorides can affect metals volatility. Efforts should be made to maintain equivalent halogen concentrations between the metals and POHC tests, as variations between the tests could add unnecessary complexity to development of permit conditions. A specific limit on maximum chloride/chlorine feed rate is required in the final permit.

3. Wastes Containing Dioxin/Furan Precursor Compounds. As mentioned previously, dioxin/furans can be formed in dry air pollution control equipment systems due to fly ash catalyzed reactions between halogens and undestroyed organic material from the furnace. Precursor compounds, such as chlorinated phenols and chlorinated aromatics, can be one source of the organic material for these reactions since existing data shows a correlation between dioxin/furan precursors in waste or fuel feeds and dioxin/furan emission rates.

If the facility plans to burn dioxin/furan precursor compounds, then those compounds should be represented in the waste feeds selected for the trial burn. The precursor compounds should ideally be present in both the low temperature POHC test and the high temperature metals test for the same reasons as the halogen concentration (generally these precursors should be used for the high halogen feed rate). If the trial burn wastes have been selected to adequately represent the types and amounts of precursor compounds to be burned at the facility, then a specific permit limit on this parameter is not necessary.

4. Halogenated wastes containing ash or metals that can lead to the catalytic formation of halogenated organic compounds. As noted earlier, certain metals are believed to catalyze low temperature reactions which can create dioxins and furans. It is important that this PIC formation mechanism be accounted for in specification of the trial burn waste. The metals which have been shown in some cases to catalyze the reactions include copper, iron, zinc, nickel, and aluminum; but copper is considered the most reactive. It is important to note that from this list, only nickel is considered a pollutant of concern with respect to human health. However, copper, zinc, and nickel are of concern with respect to wetlands ecosystem effects.

Several scenarios can be envisioned. In most instances, it is anticipated that a strong potential will exist for copper to be present in the waste stream. If copper is expected to be in any of the future waste streams to be combusted, it is suggested that the trial burn waste be doped with a known loading of copper chloride ($CuCl_2$). The precise doping level is currently being investigated but we suggest a nominal copper doping rate equivalent to 0.10 to 1.0 weight percent of the total ash content[4] [5]. If the trial burn is run at this copper chloride

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[4] Luijk, R., et al., Envir. Sci. Technol., 1994 28, 312; National Incinerator Testing and Evaluation Program:Mass Burn Technology, Quebec City, Environment Canada, Industrial Programs Branch, Ottawa, Ontario, December 1987; Kilgroe, J.D., W.S. Lanier and T.R. van Alten, Montgomery County South Incinerator Test Project: Formation, Emission, and Control of Organic Pollutants, Municipal Waste Combustion Conference Papers and Abstracts from Second Annual Specialty Conference, AWMA, Pittsburgh, PA, April, 1991; Gullett, B.K., P.M. Lemieux, J.E. Dunn, Role of Combustion and Sorbent Parameters in Prevention of PCDD and PCDF during Waste Combustion, Environ.Sci. Technol., Vol 28, No 1, 1994; Robert, S., Dioxin Formation and Control in Cement Kilns, Presented at EPA/ASME Seminar on PIC Formation and Control, RTP,NC, March 8-9, 1994

[5] The effects of metals in fly ash or inorganic compounds in stack gases have been brought into question more recently. Some metals and inorganic compounds may suppress the formation of dioxin or speed up its destruction. Metals and organic compounds which may reduce PCDD/PCDF include sulfur, sodium, calcium, and NH_3(Takacs,L., Pilot Scale Testing of Ammonia Injection Technology for Simultaneous Control of PCDD/PCDF, HCl and NOx Emissions from

doping level and if acceptable dioxin emission results are achieved, there is no reason (from a PIC perspective) to set a permit limit on the feed rate of these metals (i.e., higher levels of these metals are not expected to increase dioxin emissions). If a lower doping rate is negotiated, then the permit should limit operation to burning of waste with copper and other potential metallic catalysts loadings at or below those levels used in the trial burn. If metal doping is implemented, then it is recommended at both the high and low temperature tests since the mechanism(s) of the catalyzed reactions are unknown. An alternate scenario is when wastes fed to the unit will not contain any of the metals listed above. In that case, doping is not warranted for the trial burn but the permit should appropriately limit the composition of waste to be burned.

5. <u>Highly nitrogenated wastes which can lead to formation of nitrogenated PAHs.</u> Some nitrogenated PAHs are highly carcinogenic. Incineration of wastes containing unusually high amounts of fuel-bound nitrogen (> 5%) may lead to increased levels of nitrogenated PAHs. Of particular concern is when the nitrogen is bound in the heavy distillation fractions of the waste. Such situations may be found with coal tars or bottoms from petroleum distillation. Formation of nitrated PAHs can occur in any type of combustion system. Combustor conditions most likely to result in nitrated PAH release are when the primary flame is prematurely quenched - low temperature or too much excess air in the primary combustion chamber. For facilities burning high nitrogen wastes, the trial burn should include a test where the unit is operated at the lowest allowed temperature (or maximum excess air) while burning waste with the highest levels of bound nitrogen anticipated for that facility's normal operation. Doping of the waste with model nitrogenous compounds is generally <u>not</u> recommended since this action has the potential of changing the waste combustion characteristics depending on the surrogate used. As part of the sampling protocol for the low temperature test, it is suggested that the concentration of HCN also be determined, since it is an important PIC from decomposition of the nitrated waste.

6. <u>Difficult to burn wastes such as highly viscous liquid wastes, sludge or wastes with easily entrained solid organic particles.</u> Viscous liquids are difficult to atomize and large waste droplets in liquid waste incinerators may escape the high temperature regions of the combustor before they are completely destroyed. This process is anticipated to have similar influence on both POHC and PIC emissions. Accordingly, since this is

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Municipal Solid Waste Incineration, Municipal Waste Combustion Conference Papers and Abstracts from the Second Annual International Specialty Conference, AWMA, Pittsburgh, PA, April 1991).

covered in previous guidance, no new guidance is provided relative to selection of the trial burn waste.

7. Blended wastes with easily volatilized components. Batch-fed wastes or wastes in containers can contain substantial amounts of organic compounds that rapidly volatilize and deplete the available combustion air, forming difficult-to-destroy soot particles. PAHs and nitrogenated PAHs are commonly associated with soot particles. Trial burn test conditions for containerized waste should generally follow current guidance including consideration of the waste volatility and container size (see *Guidance on Setting Permit Conditions and Reporting Trial Burn Results*).

8. Cement Kilns with High Levels of Organic Material in the Feed. CDD/CDF may be formed in the precalciner since it appears they are formed in zones where particulate matter and organics have a potential for being "held up" for a period of time in the temperature range of 450-750°F. These compounds may be formed by devices such as preheaters, precalciners, or PM control devices. Feed conditions which are expected to pose problems are high levels of chlorine in the hazardous waste feed coupled with high levels of organics in the cement raw materials. Feed condition extremities for developing permit conditions would be represented by operations with the maximum halogen concentration in the hazardous waste feed at the same time that the raw materials contain high levels of organics.

Emission testing for the maximum levels of organics in cement kiln feeds should be completed concurrently with high halogen concentrations during both the minimum temperature (POHC) test and the maximum temperature (metals) test since the formation of PICs in the cold regions of the kiln and the air ducting system need to be evaluated. However, for many kilns it is the major source of PICs. Therefore, maximum levels or concentrations of organics as total organic carbon (TOC) in cement kiln feed stocks are recommended.

SELECTION OF REAL WASTES BASED ON TOXICITY AND QUANTITY

The previous section discussed a number of waste feed parameters which can impact two of the three subcategories of PIC emissions (i.e., PICs from partial destruction and/or recombination reactions, and PICs from fly ash catalyzed reactions, such as dioxins and furans). The last subcategory of PICs includes unburned organics which were originally present in the waste feed. For this category of PICs, it is especially important to ensure that representative waste feeds are selected for the trial burn on a site-specific basis considering the actual "real" wastes that the facility intends to burn. Since every waste generally cannot be represented during the trial burn, it is important to ensure that the trial burn wastes are selected using a "reasonable worst case" methodology. The wastes and or chemicals to be burned should be ranked based on the constituents in the various wastes that could significantly affect the risk assessment if trace amounts of those constituents went through the combustion process undestroyed. The following discussion sets forth a methodology for making this ranking. The permit writer may recommend this methodology or another method which takes into account these factors and other factors in developing the trial burn plan.

Application of this methodology results in a list of preferred constituents or wastes for use in selecting the risk assessment trial burn waste mixture. This list should only be considered a tool in selecting real wastes for the test. It is not necessary that every constituent on the list be represented during the test. Rather, the list presents a preferred ranking whereby wastes containing high quantities of constituents on the list would be considered more likely candidates for the trial burn than wastes without constituents from the list (or wastes with low quantities of those constituents). Final waste selection should include consideration of <u>both</u> the preferred constituent list and criteria specified in the "Waste Feed Condition" section of this document (hopefully, some of the compounds and criteria will overlap). Several real wastes may have to be used to meet all of the waste criteria, and/or spiking of real wastes may be necessary. The ranking methodology also does not include difficulty-of-incineration (incinerability) and other POHC selection criteria which are applicable since emissions testing for the risk assessment and DRE determinations should be combined if possible.

This methodology considers the following factors:

- <u>Quantity</u>, as reflected by data on historical feed rates and composition;

- <u>Toxicity</u>, considering both carcinogenic and non-carcinogenic effects;

- <u>Bioaccumulation Potential</u>, particularly in meat, fish and milk, given the primary importance of these routes of exposure.

An example of a waste/chemical selection process consists of the following five steps discussed below:

1. <u>Selection of Wastes Based on Quantity Burned</u> - The ten organic constituents or wastes with the highest predicted feed rates should be considered for the trial burn. This process will ensure that the hazardous organics expected to be present in the largest concentrations in the stack emissions will be included in the risk assessment.

One way of determining high-quantity organic constituents for existing facilities is to review waste profile sheets for all wastes burned in the past year of operation. The waste profile sheets typically provide a breakdown of waste composition with organic and other constituents expressed as range percents. The mid-point of the range percent for each constituent can be combined with the annual quantity burned to determine the highest-quantity constituents at a given facility. Other approaches may be appropriate for determining high-quantity constituents/wastes on a site-specific basis.

2. Selection of Constituents/Wastes Based on Quantity and Carcinogenic Potency - Constituents/wastes should be ranked on the basis of quantity and carcinogenic potency as determined by the following equation:

$$QC = (FR)(SF)$$

where:

QC = Quantity/Carcinogenic Potency Score

FR = Feed Rate (or annual quantity burned)

SF = Slope Factor (oral or inhalation, whichever is higher)

The 10 chemicals/wastes with the highest QC scores, if not already included in step 1, should be added to the list.

3. Selection of Constituents/Wastes Based on Quantity and Non-carcinogenic Toxicity - Constituents/wastes should be ranked on the basis of quantity and non-carcinogenic toxicity using the following equation:

$$QN = FR/RfD$$

where:

QN = Quantity/Non-cancer Toxicity Score

FR = Feed Rate (or annual quantity burned)

RfD = Reference Dose (oral or inhalation, whichever is smaller)

Note that the units for an oral RfD (mg/kg-bw/day) and an inhalation RAC (mg/m^3) are different. To accomplish non-carcinogenic rankings, the inhalation and oral toxicity values can be converted to similar units using the equation which was utilized to convert oral RfDs to RACs for the boiler/industrial furnace regulation as follows:

$$RAC = \frac{RfD \times \text{body weight} \times \text{correction factor}}{\text{cubic meter air breathed/day}}$$

where:

- RfD is the oral reference dose (mg/kg-bw/day);
- Body weight is assumed to be 70 kg for an adult male;
- Volume of air breathed by an adult male is assumed to be 20 cubic meter/day;
- Correction factor for route to route extrapolation is assumed to be 1.0;

As an alternative to the above transformation, the QN score could consider only the inhalation RAC, and the QNB Score below could consider only the oral RfD.

The 10 constituents/wastes with the highest QN score, if not already included in steps 1 and 2, should be added to the list.

4. <u>Selection of Constituents/Wastes Based on Quantity, Carcinogenic Potency and Bioaccumulation Potential</u> - Constituents/wastes should be ranked on the basis of quantity, carcinogenic potency, and bioaccumulation potential using the following equation:

$$QCB = (FR)(SF)(\log K_{ow})$$

where:

QCB = Quantity/carcinogenic Potency/Bioaccumulation Potential Score

FR = Feed Rate (or annual quantity burned)

SF = Slope Factor (oral or inhalation, whichever is higher)

$\log K_{ow}$ = The logarithm of the octanol-water partition coefficient, which is related to a chemical's bioaccumulation potential in milk and meat.

The 10 constituents/wastes with the highest QCB score, if not already included in steps 1, 2, or 3 should be added to the list.

5. <u>Selection of Constituents/Wastes Based on Quantity, Non-Cancer Toxicity, and Bioaccumulation Potential</u> - Constituents/wastes should be ranked on the basis of quantity, non-carcinogenic toxicity, and bioaccumulation potential using the following equation:

$$QNB = (FR)(\log K_{ow})/RfD$$

where:

QNB = Quantity/Non-carcinogenic Toxicity/Bioaccumulation Potential Score

FR = Feed Rate (or annual quantity burned)

$\log K_{ow}$ = The logarithm of the octanol-water partition coefficient

RfD = Reference Dose (oral or inhalation, whichever is smaller)

The 10 constituents/wastes with the highest QNB scores, if not already included in Steps 1, 2, 3, or 4 should be added to the list.

DEVELOPMENT OF PERMITTED OPERATING CONDITIONS

Operating conditions other than those associated with waste feed conditions can also affect the formation and emission of PICs. All thermal destruction processes operate over a range of conditions and it is important to conduct trial burn tests over the range of operating conditions for which the process is to be permitted. Combustion and flue gas cleaning device operating conditions which should be considered when defining acceptable operating conditions with respect to PICs are as follows:

1. <u>Minimum Combustion temperature and residence time.</u> Combustion reaction rates decrease with decreasing temperatures resulting in decreased POHC destruction and increased PIC formation. At lower temperatures, longer residence times are required for complete destruction of gas phase and condensed phase organics. At least one trial burn condition should be at the minimally-acceptable combustor operating temperature and residence time. (According to the regulations, residence time is determined by an indicator of combustion gas velocity.)

Low combustion temperatures can result from a number of causes: low waste heating values, high excess air levels and excessive heat extraction rates. Excessive heat extraction rates are not expected to be a problem in well designed and operated combustors. Some wastes have low heating values because of their inherent composition (high moisture content, high ash content, or chemical composition). *If low heating value wastes are burned at* *a facility then these "low BTU" wastes should be used during the trial burn tests in combination with maximum excess air rates to produce the minimum expected combustion temperatures at which the facility expects to operate. Minimum combustion temperatures could also be achieved by lowering waste feed rates. However, this method is not desirable during trial burns because of the need to maximize waste feed rates and thermal input for the ultimate permit conditions, and because lower feed rates may not result in minimum residence times.*

When low BTU wastes are not burned at a facility, it may be difficult to operate at reduced combustion temperatures without operating at abnormal combustion conditions. For moderate and high BTU value wastes, the lowest expected combustion temperatures and residence times might only be achievable by operating at maximum excess air conditions. As discussed under item 4 below, "Maximum excess air rates" should be provided as primary air.

The permit writer should also consider other factors besides waste, fuel, and air feed rates which can affect residence time. These factors include residues, including slag or ash build up in the combustion chamber as well as increases in the aqueous content and oxygen content of the waste or fuel. Trial burns should generally be tested at the highest moisture level which would be expected during the life of the permit (low temperature tests) in order to assure high moisture content will not adversely effect the combustion process or cause excessive pressures.

The minimum combustion temperature and residence time conditions should be demonstrated during the low temperature POHC test, and specific permit limits are required for both parameters. Maximum combustion gas velocity (continuously monitored as an indicator of minimum residence time) is also required to be demonstrated during the high temperature metals test, with a subsequent permit limit. Because setting a combustion velocity limit is necessary with respect to the residence time and metals testing, it is desirable to maintain the same maximum combustion gas velocity during both the POHC/PIC and metals tests.

2. <u>Amount and distribution of combustion air</u>[6]. The proper amount and distribution of combustion air is essential for efficient combustion. The amount of excess air must be sufficiently high and it must be adequately distributed to minimize the existence of fuel-rich pockets. Alternatively, overly high excess air levels or poor combustion air distribution

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[6] This discussion applies to complete combustion devices and not to pyrolytic devices which are addressed in previous trial burn guidance.

can quench combustion reactions. The range of excess air levels that will satisfy these objectives varies for each combustor technology.

The appropriate range for excess air or oxygen concentration in a combustion device is dependant on a wide variety of site specific conditions including the waste characteristics and the details of the fuel/air mixing process. For any given combustion system, there is an optimum range of excess air, but that optimum is highly site specific. As the system excess air is decreased from the optimum, the amount of oxygen available to oxidize organic constituents is reduced. Eventually, a condition is reached where the most difficult to oxidize compound will be released from the furnace. That compound is carbon monoxide (CO). Further reduction in available excess air will lead to increased CO concentrations. Thus, emission limits for CO are one method for assuring that wastes are not fed to the unit while excess air is at too low a level.

Regardless of the CO limit safeguard, some hazardous waste combustion systems have been known to operate under conditions which result in reaching or exceeding the CO permit limit. A very effective, automatic combustion control system is being widely employed which is based on continuous measurement of oxygen concentration. Some systems sense the O_2 level in the stack while others sense O_2 level while the gases are still quite hot. In either mode, a site-specific optimum excess oxygen condition may be determined. A signal from the oxygen monitor is then used to modulate a damper in the combustion air supply line or to modulate the total heat input. The overall objective is to maintain the overall fuel to air ratio as nearly constant as possible.

An automatic control system for maintaining fuel-air ratios is a highly desirable system feature for combustors burning any waste, but is especially important for units burning hazardous waste. This guidance encourages, but does not require, their inclusion as part of permitted RCRA combustion operations. Such control systems will help assure continuous operation within the defined envelope, thus minimizing the number of permit exceedances.

For combustion systems fired continuously and with discreet charges (e.g. containerized) of waste, oxygen availability is critical because the rapid release of volatile matter from each charge of waste or combustibles consumes large quantities of available oxygen. If the instantaneous oxygen demand exceeds the available oxygen, there will be a dramatic increase in the PIC generation rate as well as a change in composition of the PICs generated. Because some control systems cannot effectively respond to instantaneous O_2 demands, the trial burn must be designed to develop permit conditions which ensure that short term oxygen demand does not exceed the available oxygen supply when feeding containers (or the facility can upgrade its control system).

As stated in previous guidance, the containerized feed used during the trial burn should represent both the largest container size and the maximum amount of volatile, high BTU materials that will be fed during normal operations. A new recommendation of this guidance is that the combustor should be operated during the trial burn at a "baseline" oxygen concentration that represents the minimum level that the facility wishes to maintain as a permitted condition for treating containerized waste[7]. In this context, the baseline oxygen concentration is defined as the steady state oxygen concentration that exists in the absence of containerized feeds. When a fresh charge is added, the oxygen level will drop below that baseline, but it should not be allowed to drop below the levels measured during the trial burn, since the "worst-case" containers (i.e., maximum volatility and size) are being fed during the trial burn. Therefore, during normal operation, the unit should not go into a pyrolytic mode of operation with high emissions of CO, HC and PICs. This condition should be demonstrated during the low temperature POHC test unless it conflicts with the minimum residence time parameter (which may be achieved by using an increased amount of excess air).

Based on the trial burn results, the permit writer should establish permit conditions on container size and the minimum baseline oxygen concentration which must be met as a permitted condition for containers to be treated in the unit. The permit should also require that the container feed mechanism be automatically locked out when the measured oxygen concentration is below the established baseline. For a unit which consistently experiences CO excursions, it is recommended that both the O_2 lockout and the previously mentioned automatic combustion fuel-to-air control system be system additions, if not already part of the combustion system.

3. Maximum thermal input rates. Excessive thermal input rates (including both wastes and auxiliary fuel) can result in operation of the combustor above design operating conditions. High thermal input rates result in reduced combustion product residence times within the high temperature regions of the furnace. This situation reduces the time available for destruction of gas-phase PICs and solid organic particles entrained in the flue gas. High thermal input rates also result in increased entrainment of particulate matter and carryover of

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[7] The use of a permitted baseline oxygen concentrations may not be required in all cases since the facility may have means of quickly increasing oxygen availability (i.e., by the use of dampers). These devices or systems should be demonstrated during the trial burn.

this material into boiler passages and air pollution control devices. Prior guidance has been provided for setting trial burn test conditions representing reasonable worst case thermal input conditions. These conditions may result in reasonable worst case conditions for PIC formation.

Ideally maximum thermal input rates should be demonstrated during both the minimum temperature POHC test and the maximum temperature metals test. A maximum thermal input rate should be established in the permit based upon the measured thermal input rates during the tests. Efforts should be made to maintain equivalent thermal inputs between the metals and POHC tests, as variations between the tests could add complexity to development of permit conditions. Although it may be difficult to simultaneously achieve a maximum thermal input rate and minimum combustion temperature for the POHC test, adjustments to excess air rates and waste moisture contents can help mitigate the conflicts between these two parameters.

4. <u>Maximum Temperature at inlet to the particulate matter control device.</u> PM control devices such as electrostatic precipitators and bag houses contain large amounts of PM and under certain conditions they can act as a chemical reactor for the formation of trace organic compounds. This situation is particularly true relative to dioxins and furans. Available data shows that there is generally a net increase of CDD/CDF across particulate collection devices operated in the temperature range of 450 to 750°F. Generally, a zero change in CDD/CDF concentration across the control device simply means that removal of dioxins formed in the furnace region is matched by additional formation in the APCD. Data from several classes of combustion systems have demonstrated that CDD/CDF formation continues at lower temperature but that the formation rates are substantially reduced at temperatures below 300°F. In fact, the data indicates that reducing APCD temperature by 125°F will reduce the low temperature dioxin formation rate by an order of magnitude. Trial burns should include operations at the maximum temperature at which electrostatic precipitators or fabric filters are expected to operate and should also reflect minimally acceptable combustion conditions. With regard to the development of permitted combustion conditions, the primary concern here is to select conditions which maximize the carry-over of particulate matter to the APCD. This situation is normally achieved with maximum gas velocity <u>in the primary combustion region.</u> This condition may be distinctly different from maximum gas velocity in the overall system.

The maximum APCD inlet temperatures and maximum gas velocity parameters should ideally be demonstrated during the high temperature metals test, and specific permit limits are required for both parameters.

5. Other Conditions. Other conditions, such as flue gas cleaning equipment operating variables, can be tested at minimal-acceptable operating conditions. An example of this type of requirement would be the minimum rate at which activated carbon is injected to provide supplementary control of CDD/CDF. Another operating condition to be considered in planning trial burns for PICs is the occurrence of soot blowing. Prior guidance on this issue was provided for BIF's in "Technical Implementation for EPA's Boiler/Industrial Furnace Regulations". That same guidance should be followed relative to PIC emission evaluations.

More recently there has been discussions about the injection of additives or sorbents to the air system after the combustion device (similar to activated carbon injection). These materials include calcium, sodium, and sulfur which are believed to minimize the formation of dioxin by scavenging Cl_2. Permit writers must be aware of any injections to the air system during the trial burn and incorporate them into the permit as appropriate.

APPLICATION OF DATA

Traditionally, trial burns have included special tests for metals where the system operating temperature is maximized and tests for POHC emissions where system temperatures are minimized. For the purposes of the risk assessment, it is recommended that PICs be quantified under both sets of operating conditions. With regard to use in the risk assessment, the emission value used for PIC and metal constituents should be an average of results from three runs completed for a given waste or operating condition. The test condition which gives the highest risk should be the values used in the risk assessment. This procedure will likely result in the need to calculate the risk for more than one test condition if it is not obvious which test condition represents the higher risk.

If there are great differences in the results for the individual runs in a set of test runs or conditions, the average value may not be appropriate. The cause of the disparity should be determined and a more appropriate value may be selected by the permit writer or he/she may require a retest.

The above discussion does not revise the previous methodology for determining noncompliance with emissions limits. Historically, this determination is based on a single run. Therefore, each run of a test must pass to be permitted at that condition. There is no change in this approach at this time.

PARTICULATE SIZE DISTRIBUTION

Both the deposition and vegetative uptake algorithms used in the risk assessment models require information on particle size. Although site-specific ambient particle size data that is representative of the interaction of the combustion device particles and the background aerosol is preferred, such data may be difficult to obtain. Particle size distribution of the emissions may be measured directly, or may be estimated from information in the "Compilation of Air Pollutant Emission Factors" (AP-42) (available from the Government Printing Office). The information in AP-42 is applicable mainly to BIFs.

EXEMPTIONS

It is important to note that planning and execution of trial burns and development of risk assessments based on trial burn results is extremely involved and expensive, and that under special conditions, it <u>may</u> not always be justified. Earlier guidance and regulations for trial burn planning recognized this fact and gave permit writers flexibility to forego DRE trial burns under three separate scenarios. These scenarios included (1) Incinerators burning waste with no or insignificant hazardous constituents, (2) BIF's qualifying for the low risk waste exemption, and (3) boilers under special operating conditions. Under conditions where, in the opinion of the permit writer, no DRE trial burn is necessarily required, consideration may also be given to excluding the facility from PIC trial burn testing. In screening such facilities, the permit writer must carefully evaluate any available data (including historical PIC emissions data, waste types, presence of halogens, volumes, and toxicity) from similar facilities burning similar waste. Special attention should be given to any data concerning dioxin and furan emissions from similar facilities, including similar units burning non-hazardous wastes. In screening such data, the permit writer must be particularly mindful of the guidance presented in the previous sections to assure that provided data represents a realistic assessment of anticipated reasonable worst case emissions. Based on such a screening review, which must include historical data on CO and/or HC, a waiver of the PIC trial burn could be in order. Until further guidance is developed on this issue, it is recommended that permit writers considering such an exemption consult with OSW.

TRIAL BURN

EXAMPLE TEST MATRIX

	PIC/POHC Test	Metals Test	Permit Condition (Y/N)
Feed Parameter			
Organic Types	Representative	Representative	N
Nitrated Waste	Representative	Representative	N
Metal Catalyst	Maximize $CuCl^2$	Representative	Y as appl.
Halides/Halogens	Maximum	Maximum	Y
Ash	Maximum	Maximum	Y
POHC	Based on POHC Selection Criteria	Same as POHC/PIC Test	N
BIF Metals	Representative	Maximum	Y
Volatility	Maximum	Representative	N
Precursors	Representative	Representative	N
TOC of Kiln Feed	Maximum	Representative	N?
Combustion Parameters			
Container Size	Maximum	Maximum	Y
Combustion Temp.	Minimum	Maximum	Y
Thermal Input	Max. if poss.	Maximum	Y
Combustion Gas Vel.	Maximum	Maximum	Y
Oxygen Content	Minimum	Minimum	Y for Batch
Soot Blowing	Representative	Representative	N

	PIC/POHC Test	Metals Test	Permit Condition (Y/N)
APCD Conditions			
Temperature	Representative	Maximum	Y
ΔP	Minimum	Minimum	Y
Rapping or Cleaning Rate	Normal	Maximum	

Other APCD Parameters - As per previous guidance.

Resource Documents:

Guidance on Setting Permit Conditions and Reporting Trial Burn Results; EPA/625/6-89/019, January 1989.

Technical Implementation Document for EPA's Boiler and Industrial Furnace Regulations; EPA/530-R-92-011; NTIS# PB92-154 947, March 1992.

Combustion Emissions Technical Resource Document (Draft); EPA, April 1994

DRAFT

April 15, 1994

Attachment C

GUIDANCE FOR PERFORMING SCREENING LEVEL RISK ANALYSES AT COMBUSTION FACILITIES BURNING HAZARDOUS WASTES

Office of Emergency and Remedial Response

Office of Solid Waste

1. INTRODUCTION

This document provides guidance for performing a screening level analysis of direct and indirect human health risks from combustion emissions. The screening procedure is intended to give a conservative estimate of the potential risk in order to determine whether a more detailed site-specific assessment is warranted. The screening guidance provides information on the constituents, exposure scenarios, indirect pathways, and parameter values that are needed for estimating risk. The document is designed as a kind of "workbook" that is clear, concise, and simple to use.

The screening procedure is based on the guidance in the January, 1990 interim final report *Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions* (EPA/600/6-90/003 and referred to as the Indirect Exposure Document), the draft Addendum to the Indirect Exposure Document (dated November 10, 1993), and the draft implementation guidance entitled "Implementation Guidance for Conducting Indirect Exposure Analysis at RCRA Combustion Units" (dated April 22, 1994 and referred to as the Implementation Guidance). In the interest of simplicity, the procedure has been streamlined by reducing the number of algorithms that need to be evaluated, while retaining the degree of conservatism appropriate for a screening level analysis.

The screening guidance specifies the particular exposure scenarios that should be evaluated and provides default values for most input parameters. In addition, the screening guidance also allows the flexibility to use available site-specific information to modify certain assumptions. For example, site-specific land use information may be used to determine that certain assumptions regarding the exposure scenarios are implausible (e.g., that exposure occurs at the points of maximum air concentration and maximum deposition) and to make alternative assumptions (e.g., to identify locations at which the exposure scenarios used for the screening analysis are plausible). If the final estimated risk is below levels of concern, then there is good reason to conclude that further analysis of the risk from stack emissions is unnecessary.

The primary focus of the screening guidance is on indirect exposures. However, in order to characterize the risk from stack emissions it is necessary to characterize the risk from direct inhalation exposures as well. The screening guidance, therefore, includes a brief discussion of estimating risk from direct inhalation exposures. It is important to recognize that the constituents for which direct inhalation exposures are of primary concern may be different from (and generally more numerous than) those for indirect exposures.

The endpoints of the screening analysis are estimates of individual risk for several exposure scenarios. The exposure scenarios selected for the screening analysis are considered to be the most significant ones for combustion sources. For each scenario, the risk estimates are based on combining exposures and risk for an individual constituent across several pathways. Where appropriate, risk from multiple constituents are also combined to provide estimates of overall risk for each exposure scenario.

As indicated in the text box, in the following sections the document gives a general overview of the screening approach (Section 2), discusses the required air dispersion and deposition modeling and input parameters (Section 3), presents the equations to use and gives default parameter values for calculating media concentrations for each of the pathways that are associated with indirect exposures (Section 4), provides all necessary chemical-specific parameter values (Section 5), and explains how to characterize risk for each of the exposure scenarios in the screening analysis (Section 6).

Section 1.	**Introduction**
Section 2.	**Overview**
Section 3.	**Air Dispersion and Deposition Modeling**
Section 4.	**Indirect Exposure Pathway Equations**
Section 5.	**Chemical-Specific Parameters**
Section 6.	**Risk Characterization**

2. OVERVIEW

This section gives an overview of the screening approach to the analysis of indirect and direct exposures to combustion emissions. This section highlights key aspects of the screening guidance, including constituents to evaluate, exposure scenarios that form the basis of the analysis, atmospheric dispersion and deposition modeling that represents the initial fate and transport of constituents in the environment, fate and transport of constituents in soil, terrestrial food chain, and aquatic food chain pathways that lead to indirect human exposures, and characterization of risk to individuals from both direct and indirect exposures.

2.1 Constituents

The screening approach for analyzing indirect exposures to combustion emissions focuses on a limited number of constituents. These constituents have been selected based on an analysis of their potential to pose increased risk by means of one or more of the indirect exposure pathways. The constituents selected include metals and organic compounds that are believed to be products of incomplete combustion (PIC's). Among the constituents selected are those that are considered to present the highest risks to human health via indirect exposures.

For direct inhalation exposures, however, there are many constituents that could pose increased risk. Therefore, the screening analysis should include all constituents for which stack emission data and inhalation health benchmarks exist, i.e., unit risk factors or reference concentrations (RfCs), for the purpose of estimating risk from direct inhalation exposures.

The constituents to be included in the indirect exposure assessment are the following:

Dioxins and Dioxin-like Compounds

2,3,7,8-substituted Polychlorinated dibenzo(p)dioxin congeners (2,3,7,8-PCDD's)
2,3,7,8-substituted Polychlorinated dibenzofuran congeners (2,3,7,8-PCDF's)

All emissions of 2,3,7,8 substituted polychlorinated dibenzo(p)dioxins and dibenzofurans are converted to 2,3,7,8-tetrachlorodibenzo(p)dioxin (2,3,7,8-TCDD) toxicity equivalents following EPA's *Interim Procedures for Estimating Risks Associated with Exposures to Mixtures of Chlorinated Dibenzo-p-Dioxins and Dibenzofurans (CDDs and CDFs)* (U.S. EPA, 1989). All congeners are then modeled using the fate and transport properties of 2,3,7,8-TCDD.

Polycyclic Aromatic Hydrocarbons (PAH's)

Benzo(a)pyrene
Benz(a)anthracene
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Chrysene
Dibenz(a,h)anthracene
Indeno(1,2,3-cd)pyrene

Based on comparative potency estimates provided in EPA's *Provisional Guidance for the Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons* (Office of Health and Environmental Assessment, 1993) emissions of these PAH's are converted to benzo(a)pyrene toxicity equivalents (BaP-TEQ). All PAH's are then modeled using the fate and transport properties of benzo(a)pyrene.

Polychlorinated Biphenyls (total PCB's)

total Polychlorinated biphenyls (all congeners)

All polychlorinated biphenyl congeners (209 congeners) are treated as a mixture having a single carcinogenic potency, as recommended in EPA's *Drinking Water Criteria Document for Polychlorinated Biphenyls (PCBs)* (U.S. EPA, 1988).

Nitroaromatics

1,3-Dinitro benzene
2,4-Dinitro toluene
2,6-Dinitro toluene
Nitrobenzene
Pentachloronitrobenzene

Phthalates

Bis (2-ethylhexyl) phthalate
Di(n)octyl phthalate

Other Chlorinated Organics

Hexachlorobenzene
Pentachlorophenol

Metals

Arsenic
Beryllium
Lead
Mercury

2.2 Emission Estimates

The draft Addendum and the Implementation Guidance provide guidance on estimating emissions from combustion sources. This guidance should be followed when determining the emission rates to use in the screening analysis.

2.3 Human Exposure Scenarios

Four human exposure scenarios have been developed for use in the screening analysis: a subsistence farmer, a subsistence fisher, an adult resident, and a child resident. These exposure scenarios differ primarily in consumption rates of contaminated foods. In particular, subsistence farmers consume more contaminated beef and milk than the general adult population and subsistence fishers consume more contaminated fish than the general population. While the general population may also consume contaminated beef, milk, and fish, a much larger fraction of the consumption of these foods is likely to be contaminated for a subsistence farmer or fisher because subsistence farmers and fishers may obtain these foods from a single source. Table 2.1 presents the rates of consumption of contaminated food, ingestion of contaminated soil, and inhalation of polluted air for each of the four exposure scenarios.

All of these exposure scenarios should be evaluated for making screening level estimates of risk. However, site-specific information (e.g., local land use data) may indicate that the subsistence farmer or fisher or adult resident or child may not be exposed at the locations of maximum air concentration and maximum deposition. In such cases, these scenarios should continue to be included in the screening analysis based on alternative locations of exposure, as described in Section 3. The exposure scenarios are described in the following paragraphs. Guidance on characterizing the risk for each scenario is provided in Section 6.

Subsistence Farmer

In the subsistence farmer scenario, an adult farmer is exposed via consumption of homegrown beef and milk, consumption of homegrown vegetables, incidental soil ingestion, and direct inhalation of vapors and particles. The subsistence farmer is assumed to raise cattle for both beef and milk consumption and grow crops for home consumption. Site-specific information could be used to modify these assumptions.

Table 2.1. Consumption Rates and Fraction Contaminated Used in Exposure Scenarios

Contaminated food or media	Exposure Scenario							
	Subsistence Farmer		Subsistence Fisher		Adult Resident		Child Resident	
	Rate	Frac.	Rate	Frac.	Rate	Frac.	Rate	Frac
Beef (g/day)	100	0.44	NA	NA	NA	NA	NA	NA
Milk (g/day)	300	0.40	NA	NA	NA	NA	NA	NA
Fish (g/day)	NA	NA	140*	1	NA	NA	NA	NA
Above-ground vegetables (g DW/day)	24	0.95	24	0.25	24	0.25	5*	0.25
Root vegetables (g DW/day)	6.3	0.95	6.3	0.25	6.3	0.25	1.4*	0.25
Soil (mg/day)	100	1	100	1	100	1	200	1
Air (m^3/day)	20	1	20	1	20	1	5*	1

Notes: DW = dry weight NA = not applicable * = provisional value for interim use only
All values from the Exposure Factors Handbook (U.S.EPA, 1990a).
Units shown are for consumption rate; all fractions contaminated are dimensionless.

Consumption rates for contaminated beef, milk, above-ground vegetables, and root vegetables are representative of a typical subsistence farmer, rather than the general population. Exposures to crops include consumption of both above-ground vegetables and root vegetables. The incidental soil ingestion rate and the inhalation rate are typical for adults.

Subsistence Fisher

In the subsistence fisher scenario, an adult fisher is exposed via consumption of contaminated fish and homegrown vegetables, incidental ingestion of soil, and direct inhalation of vapors and particles. Both finfish and shellfish are considered. Fish consumption rates are intended to be representative of a typical subsistence fisher, rather than the general population. However, limited data are available on rates of fish consumption by subsistence fishers. Therefore, the consumption rate given in Table 2.1 is provisional and is intended for interim use only. Consumption rates for above-ground vegetables and root vegetables and the incidental soil ingestion and inhalation rates are typical for adults.

Adult Resident

In the adult resident scenario, an adult is exposed via consumption of homegrown vegetables, incidental soil ingestion, and direct inhalation of vapors and particles. Exposures to homegrown vegetables include both above-ground vegetables and root vegetables.

Consumption rates for above-ground vegetables and root vegetables and the incidental soil ingestion and inhalation rates are typical for adults.

Child Resident

In the child resident scenario, a child is exposed via consumption of homegrown vegetables, incidental soil ingestion, and direct inhalation of vapors and particles. Exposures to homegrown vegetables include both above-ground vegetables and root vegetables. The incidental soil ingestion rate is typical for children. Consumption rates for above-ground vegetables and root vegetables and inhalation rates that are typical for children are not available; the values given in Table 2.1 are provisional and are intended for interim use only.

2.4. Air Dispersion and Deposition Modeling

The COMPDEP air dispersion and deposition model is used to estimate air concentrations, and wet and dry deposition rates. The model requires hourly surface wind, cloud cover, and precipitation observations and twice daily mixing heights. The meteorological data should be representative of conditions at the site. The model is run once using a "unit" emission rate (i.e., 1 gram/second) with both dry and wet deposition options selected. The results of this run are used for both air concentrations and deposition rates of particles and vapors. The values obtained using the unit emission rate are adjusted to chemical-specific air concentrations and deposition rates using chemical-specific emissions rates. Vapor-particle partitioning is not considered as part of the air dispersion and deposition modeling; rather, adjustments are made to the modeled air concentrations to account for vapor-particle partitioning as part of the indirect fate and transport pathways analysis in Section 4.

The point of maximum combined wet and dry deposition, as output by the COMPDEP model, is used as the point of departure for all indirect pathway exposures. If the risk estimated from this very conservative assumption does not indicate a problem, no further analysis is necessary. However, site-specific information (e.g., land use data) may be used to determine the locations of the agricultural field and the watershed of concern and the size of the watershed. (A default watershed size is provided if the requisite information is not available locally.) It is recommended that the locations of maximum air concentration and maximum combined wet and dry deposition be used for the child and adult resident exposure scenarios unless these points are predicted to occur at locations where it is clearly implausible that a residence could be located (e.g., over a large lake or within a large industrial area).

Direct inhalation exposure is evaluated at the location of the maximum air concentration. The maximum air concentration is assumed to be collocated with the point of maximum combined wet and dry deposition. However, this assumption may be modified if site-specific information is used to identify alternative locations for use in evaluating the exposure scenarios.

2.5 Indirect Exposure Pathways

For screening purposes, indirect exposures include ingestion of above-ground vegetables, root vegetables, beef and milk, fish and shellfish, and soil. Contaminants in combustion emissions may reach these media or foods by many pathways. The pathways that provide the highest media or food concentration have been selected for use in the screening analysis. Different pathways give the highest concentrations for different constituents. For example, soil erosion gives the highest water concentration for some constituents, while runoff gives the highest water concentration for other constituents. In these cases, constituent-specific guidance is provided in Section 4.

For the indirect exposure pathways analysis, a combination of two parameters that have the greatest impact on media or food concentrations are set at "high end" values, while other parameters are set at typical or "central tendency" values. This will provide a high end estimate of the concentration of the constituents in the media or food. Tables in Section 4 and Section 5 provide all parameter values that need to be used in the screening analysis.

The indirect exposure pathways selected for screening analyses are described in the following paragraphs.

Above-ground Vegetables

Above-ground vegetables are ingested by humans and cattle. Cattle ingestion of above-ground plants is discussed below in the sections for beef and milk. For human ingestion of above-ground vegetables, the following two pathways of contaminant transport are included: deposition of particle phase contaminants directly onto plant surfaces and direct transfer of vapor phase contaminants into plant material. One or the other of these pathways may dominate or be inapplicable for specific constituents. Constituent-specific guidance is provided in Section 4 on which of these pathways should be considered.

Root Vegetables

For ingestion of root vegetables by humans, contamination by root uptake of contaminants deposited on soil is included. Because this is the only pathway for root vegetables, it should be included for all constituents (except lead).

Beef

For ingestion of beef, three pathways are included. The first is deposition directly onto forage plant surfaces followed by cattle consuming contaminated forage and bioaccumulation in muscle tissue. This pathway should be included for all constituents (except lead). The second pathway is direct transfer of vapor phase contaminants into forage plant material followed by cattle consuming contaminated forage and bioaccumulation in muscle tissue; this pathway should be included only for selected constituents, as indicated in Section 4. The third pathway is incidental ingestion of soil by cattle and bioaccumulation in muscle tissue. This pathway should be included for all constituents (except lead).

Milk

For ingestion of milk, three pathways are included. The first is deposition directly onto forage plant surfaces followed by dairy cattle consuming contaminated forage and bioaccumulation in milk. This pathway should be included for all constituents (except lead). The second pathway is direct transfer of vapor phase contaminants into forage plant material followed by dairy cattle consuming contaminated forage and bioaccumulation in milk; this pathway should be included only for selected constituents, as indicated in Section 4. The third pathway is incidental ingestion of soil by dairy cattle and bioaccumulation in milk. This pathway should be included for all constituents (except lead).

Fish

For ingestion of fish, the following pathways are included:

- deposition onto the watershed, followed by soil erosion into the waterbody, followed by bioaccumulation of contaminant from total water column concentration to fish tissue;
- deposition onto the watershed, followed by soil erosion into the waterbody, followed by deposition into the bed sediment, followed by bioaccumulation in fish tissue;
- deposition onto the watershed, followed by runoff into the waterbody, followed by bioconcentration of contaminant from dissolved water concentration to fish tissue;
- and deposition directly onto the waterbody, followed by bioaccumulation of contaminant from total water column concentration to fish tissue

Which of these pathways should be included depends on the constituent, as indicated in Section 4.

Soil

For incidental ingestion of soil by adults and children, contamination by deposition onto soils should be included in the screening analysis for all constituents.

2.6 Risk Characterization

The screening analysis provides estimates of risk that are based on a combination of high end values for some parameters and central tendency values for other parameters. The following high end assumptions are used:

- Emissions from the combustion source for each constituent generally represent high end values. The *Implementation Guidance for Conducting Indirect Exposure Analysis at RCRA Combustion Units* provides guidance for determining metals and organic emissions.

- Air concentration and deposition from the locations of the maximum air concentration and maximum combined wet and dry deposition are used as the point of departure. However, alternative locations may be considered. Additional guidance for identifying alternative locations is provided in Section 3.

- Two fate and transport parameters in the indirect pathways analysis are set to high end values. The two high end parameters are the two most sensitive parameters (or groups of related parameters) that have been determined by sensitivity analysis. The two high end parameters depend on the exposure pathway. Specific guidance on high end parameters for each pathway is provided in Section 4.

- The exposure duration for each exposure scenario is set to a high end value. The values for exposure duration are given in Section 6.

Use of these assumptions with the exposure scenarios described in Section 2.3, together with simplifying conservative assumptions in the exposure pathways analysis, will ensure that the results represent high end or bounding estimates of risk. If there actually are subsistence farmers, subsistence fishers, or residents in the area of concern, the risk estimates will represent conservative high end estimates of risk. However, if there are not subsistence farmers, subsistence fishers, or residents in that area, the risk estimates will represent bounding estimates of risk for the general population.

Additivity of Pathways Within an Exposure Scenario

The exposures from the indirect pathways should be combined for each scenario and constituent. Therefore, for the subsistence farmer scenario, exposures from ingestion of beef, milk, above-ground vegetables, and root vegetables, and incidental soil ingestion should be added together for each constituent. For the subsistence fisher, exposures from ingestion of fish, above-ground vegetables, root vegetables, and soil should be added together for each constituent. In the adult and child resident scenarios, exposures from ingestion of above-ground vegetables and root vegetables and incidental soil ingestion should be added together. However, adult exposure and child exposure are considered separately and should not be combined. The end result is one oral exposure (dose) for each scenario and constituent. Given these exposures, a carcinogenic risk and, for non-cancer effects, a hazard quotient is calculated for each scenario and each constituent. (Note that a hazard quotient cannot be calculated for lead, as no health effects benchmark has been established for lead. Therefore, only soil concentrations are calculated for lead.)

Exposures from the direct exposure pathway should not be added to those from the indirect pathways. This is because the risk from the direct exposure pathway, which results from the inhalation route of exposure, is determined separately from the risk from the indirect pathways, which result from the oral route of exposure. However, for carcinogens, the risk from direct exposures to a constituent is added to the risk from indirect exposures to the constituent for each exposure scenario.

Additivity of Constituents Within an Exposure Scenario

The exposure scenarios described in Section 2.3 involve exposures to a variety of constituents. For the purpose of the screening analysis, cancer risks from carcinogenic constituents are added together to estimate the total carcinogenic risk. However, hazard quotients for noncarcinogens should be added together only if the health effects caused by exposure to the constituents are similar (e.g., the constituents affect the same target organ). Specific guidance regarding the additivity of hazard quotients for different constituents and the calculation of hazard indices via the oral route of exposure (i.e., from indirect exposures) is provided in Section 6.

3. AIR DISPERSION AND DEPOSITION MODELING

The COMPDEP air dispersion and deposition model (version 93340) is used to estimate air concentrations, and wet and dry deposition rates. The model FORTRAN code, executable versions, sample input and output files, and documentation are available for downloading from the Support Center for Regulatory Air Models bulletin board system (SCRAM BBS) in the Other Models section. The SCRAM BBS is a part of the Office of Air Quality Planning and Standards Technology Transfer Network (OAQPS TTN). Accessing information for SCRAM is contained in the table box. A description of the model is provided with the model package.

Resources for Model Code

COMPDEP model PCRAMMET meteorological preprocessor Precipitation preprocessor (not yet available)	OAQPS' Support Center for Regulatory Air Models Bulletin Board System (SCRAM BBS) Other Models section In the first call the user provides registration information. Once registered, the user has full access to the BBS.	(919) 541-5742 24 hrs/day, 7 days/wk except Monday a.m. 1200 - 9600, 14.4K Baud Line settings: 8 data bits no parity 1 stop bit Terminal emulation: VT100 or ANSI System operator: (919) 541-5384 (normal business hours EST)

Three input files are used for COMPDEP. The control file (*.INP) is an ASCII file which contains the model option settings, source parameters, and receptor locations. Two binary format meteorological input files are also used. The meteorological file (*.MET) contains hourly values of wind speed, wind direction, stability class, mixing height, and ambient air temperature. The precipitation file (*.PPT) contains hourly values of precipitation type and intensity.

The output available from COMPDEP includes the long-term average air concentration for each receptor in units of $\mu g/m^3$, and the long-term average values for each receptor of dry deposition, wet deposition, and combined wet and dry deposition in units of g/m^2-yr.
The averages are taken over the period of record of the meteorological data, as input to the model. If one year of meteorological data are input, the values at each receptor will be annual averages. The model output identifies the highest value of air concentration, dry deposition, wet deposition, and combined wet and dry deposition and the associated receptor. The model

output also provides the arithmetic average value across all receptors of air concentration, dry deposition, wet deposition, and combined wet and dry deposition.[1]

3.1 Control File

This section discusses the control file (*.INP) and provides default values for the parameters which are not facility or site-specific. The user's instructions provided with the COMPDEP model code contain more detailed information on using the model. Table 3.1 lists all of the inputs required for running COMPDEP, including recommended default values.

Table 3.1 Inputs for COMPDEP Modeling

Variable	Input	Units/Explanation
Horizontal scale factor	0.001	converts horizontal units to kilometers
Vertical scale factor	1.0	converts vertical units to meters
Pollutant half-life	0.0	no pollutant decay, (seconds)
Modeling options:		
Terrain adjustment	1	use terrain adjustment
Stack tip downwash	0	use stack tip downwash
Plume rise	0	calculate distance dependent rise
Buoyancy induced dispersion	1	use buoyancy induced dispersion
Calms processing	1	use calms processing routine
Dry deposition	1	use dry deposition
Wet deposition	1	use wet deposition
Building wake effects	1	include building wake effects
Anemometer height	10.0	meters
Array of wind speed profiling factors	0.07, 0.07, 0.1, 0.15, 0.35, 0.55	adjustments for Pasquill-Gifford stability classes A through F, unitless
Array of terrain adjustments	0.5, 0.5, 0.5, 0.5, 0.0, 0.0	adjustments for Pasquill-Gifford stability classes A through F, unitless
Distance limit for plume centerline	10.0	meters
Building height	facility-specific	meters
Building width	facility-specific	meters

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[1] The model also computes a geometric mean value which takes the logarithm of the concentration and deposition values. The geometric mean should not be used in place of the arithmetic average for estimating areal average deposition. The use of areal average deposition is discussed in Section 3.5, Receptor Placement.

Table 3.1 Inputs for COMPDEP Modeling

Variable	Input			Units/Explanation
Source coordinates	0.0, 0.0			X, Y coordinates of stack in meters
Stack height	facility-specific			meters
Stack gas exit temperature	facility-specific			degrees kelvin
Stack inner diameter	facility-specific			meters
Stack gas exit velocity	facility-specific			meters/second
Ground elevation at stack	site specific			meters See Section 3.6, Terrain
Particle Size categories	3			number of categories, unitless
Particle density	1.0			grams/cubic centimeter
Array of particle size classes	1.0	6.0	15.	mean particle diameter, microns
Emission rate	1.0			grams/second
Fraction of emissions in each particle size class	.78	.19	.03	fraction of emissions in particle size class by surface area, unitless
Receptor locations - 1st run				Polar array along 22.5° radials, spaced at logarithmic intervals out to 10,000 m from the stack, converted to Cartesian coordinates (X, Y values). See Section 3.5, Receptor Placement
Name	optional			
X (east) coordinate	See Table 3.3			
Y (north) coordinate	See Table 3.3			
Height above ground	0.0			
Ground elevation	0.0 or terrain height			See Section 3.6, Terrain
Receptors - watershed - 2nd run				If using the default watershed, place receptors spaced every 500 m over a 7000 m x 7000 m square centered on the maximum combined deposition receptor from the 1st run. If using the actual watershed, place receptors spaced every 500 m within the boundaries of the watershed at the actual location of the watershed. See Section 3.5, Receptor Placement
Name	optional			
X (east) coordinate	default or site specific			
Y (north) coordinate	default or site specific			
Height above ground	0.0			
Ground elevation	0.0 or terrain height			See Section 3.6, Terrain

Table 3.1 Inputs for COMPDEP Modeling

Variable	Input	Units/Explanation		
Surface roughness length	See Table 3.4	See Section 3.8, Surface Roughness		
Precipitation scavenging coefficients	Particle Size (μm)	Precipitation Intensity		
		light (s^{-1})	moderate (s^{-1})	heavy (s^{-1})
	1	2.20E-4	5.60E-4	1.46E-3
	6	1.80E-4	8.93E-4	4.64E-3
	15	9.69E-3	9.69E-3	9.69E-3

The sample input file which is downloaded with the model (EXAMPLE.INP) can be used as a starting point when developing the control file. Example 3.1 illustrates the control file as it should be prepared for the screening analysis. The input parameters which should be replaced by facility-specific or site-specific values are italicized in Example 3.1.

The changes that should be made to the EXAMPLE.INP file are as follows:

1) TRANSITIONAL PLUME RISE: This option should be set to 0 so that transitional plume rise will be calculated when the terrain heights exceed the top of the stack. (COMPDEP defaults to using the transitional plume rise when the building downwash algorithm is selected.)

2) STACK AND BUILDING PARAMETERS: Facility-specific values for stack height, stack diameter, exit temperature, and exit velocity are required. Also required are facility-specific values for building height and building width.

3) RECEPTOR LOCATIONS: The recommended receptor locations are discussed in Section 3.5.

4) RECEPTOR ELEVATIONS: Site-specific terrain elevations (and stack base elevation) are needed in areas of complex terrain or where other terrain features are significant, as discussed in Section 3.6.

5) PARTICLE SPECIFIC INPUTS: The recommended particle size categories, fraction of emissions in each category, and particle density are listed in Table 3.2.

Table 3.2 summarizes the changes to the EXAMPLE.INP file.

Example 3.1 COMPDEP input file for the screening analysis. Inputs in bold italics are replaced by facility or site specific values.

```
EXAMPLE RUN OF COMPDEP FOR COMBUSTION STRATEGY SCREENING ANALYSES
RECEPTORS AT DEFAULT LOCATIONS (ON RADIALS AT 22.5 DEGREE INTERVALS)
MODELING FOR AIR CONCENTRATIONS AND DRY AND WET DEPOSITION FLUXES
89,1,1,.001,1.0,0.,0
1,0,0,1,1,1,1,1
10,.07,.07,.1,.15,.35,.55,.5,.5,.5,.5,0.,0.,10.,20.,30.
0.,0.,25.,400.,1.5,10.,0.,3,1.0
1.,6.,15.
UNIT EMISSIONS             1.
0.78,0.19,0.03
ENDP
0,100          0.         100.       0.      0.
22,100        38.          92.       0.      0.
45,100        71.          71.       0.      0.
67,100        92.          38.       0.      0.
90,100       100.           0.       0.      0.
112,100       92.         -38.       0.      0.
135,100       71.         -71.       0.      0.
157,100       38.         -92.       0.      0.
180,100        0.        -100.       0.      0.
202,100      -38.         -92.       0.      0.
225,100      -71.         -71.       0.      0.
247,100      -92.         -38.       0.      0.
270,100     -100.           0.       0.      0.
292,100      -92.          38.       0.      0.
315,100      -71.          71.       0.      0.
337,100      -38.          92.       0.      0.
0,150          0.         150.       0.      0.
22,150        57.         139.       0.      0.
45,150       106.         106.       0.      0.
67,150       139.          57.       0.      0.
90,150       150.           0.       0.      0.
.
.
.
247,9999   -9239.       -3827.       0.      0.
270,9999  -10000.           0.       0.      0.
292,9999   -9239.        3827.       0.      0.
315,9999   -7071.        7071.       0.      0.
337,9999   -3827.        9239.       0.      0.
ENDR
0.3
2.20E-4,5.60E-4,1.46E-3
1.80E-4,8.93E-4,4.64E-3
9.69E-3,9.69E-3,9.69E-3
```

Note: See Table 3.2 on the highlighted changes required.

Table 3.2 Changes from EXAMPLE.INP for Screening Analysis

Variable	Variable Name *	Screen Value	EXAMPLE.INP	Units
Title - 3 lines	LINE1, LINE2, LINE3	facility-specific	EXAMPLE RUN FOR COMPDEP....	
Starting year	IDATE(1)	site specific	89	2-digit
Plume rise	IOPT(3)	0	1	
Building height	HB	facility-specific	20.0	meters
Building width	WB	facility-specific	30.0	meters
Stack height	SOURCE(3)	facility-specific	25.0	meters
Stack temperature	SOURCE(4)	facility-specific	400.0	degrees K
Stack diameter	SOURCE(5)	facility-specific	1.5	meters
Stack gas exit velocity	SOURCE(6)	facility-specific	10.0	meters/sec
Stack ground level	ELP	facility-specific	0.	meters
Particle density	PARTDNS	1.0	1.8	g/cm^3
Array of particle sizes	PARTSZ	1., 6., 15.	1., 6.78, 20.	size range median, μm
Fraction of emissions in each particle class	PFRACT	.78, .19, .03	.85, .10, .05	unitless
Receptor locations and ground elevations	RREC,SREC,ELR	polar array out to 10 km Cartesian coordinates See Table 3.6 Also site specific (optional)	polar array out to 50 km Cartesian coordinates	meters
Surface roughness	Z0	site specific	0.3	meters

* See COMPDEP documentation which accompanies the model code.

3.2 Meteorologic Data

It is important that appropriate meteorological data be used. Data from nearby weather stations should be evaluated to determine which data are most representative of conditions at the site. The *Guideline on Air Quality Models* (EPA, 1993b) recommends that five years of meteorological data be used for making long-term estimates of ambient air concentrations. If five years of data are not available, as many years of complete data as are available should be used. A minimum of one year of data is required.

Required meteorological surface observations include hourly wind speed, wind direction, ambient temperature, cloud cover, and precipitation type and amounts. Also required are

Resources for Meteorological Data

Meteorological data	National Climatic Data Center (NCDC), Asheville, NC	National Climatic Data Center Federal Building 37 Battery Park Avenue Asheville, NC 28801-2733 Customer Service: (704) 271-4871

File type:	File name:
Hourly precipitation amounts	NCDC TD-3240
Hourly surface observations with precipitation type	NCDC TD-3280
Twice daily mixing heights from nearest station	NCDC TD-9689 (also available on SCRAM BBS for 1984 through 1991)

estimates of day and nighttime (twice daily) mixing heights. Unless more representative data are available, the most common source of meteorological data is the National Climatic Data Center (NCDC) in Asheville, NC. Information is given in the text box on how to contact NCDC for meteorologic information. The twice daily mixing height files are available on SCRAM for the years 1984 to 1991 for National Weather Service (NWS) locations which take routine upper air soundings. Local effects are less pronounced in upper air soundings, and given the large spacing between stations taking soundings, data from the closest upper air station should normally be used.[2]

Preprocessors (PCRAMMET or MPRM) for formatting the second input file (*.MET) required for COMPDEP are available for downloading from SCRAM. The data inputs for these preprocessors are hourly values of wind speed, wind direction, ambient temperature, sky cover, and twice daily mixing heights. The preprocessor creates a file in binary format which contains hourly wind speed, wind direction (randomized), atmospheric stability class, temperature, and mixing height.

A precipitation file which couples the type of precipitation from the surface observations with the amount of precipitation observed is the third input file (*.PPT) required for COMPDEP, a file which is also in binary format. The information in the text box specifies the type of data required to prepare the precipitation file. The data are available through the NCDC

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[2] NWS surface data are available on SCRAM; however, these files have been shortened and the precipitation type has been deleted. Therefore, these files cannot be used for preparing the precipitation file (*.PPT) for input to the COMPDEP model.

for NWS and other locations which routinely take weather observations. The documentation in the COMPDEP model package contains instructions for preparing the inputs for the precipitation file.[3]

3.3 Emission Rates

For the screening analysis, the model is run once using a "unit" emission rate of 1 gram/second, with both dry and wet deposition options selected. No distinction is made between particles and vapors for the COMPDEP model run. This is a conservative, simplifying assumption. The results of this run are used for both air concentrations and deposition rates of particles and vapors. Adjustments to the modeled air concentration and deposition to account for the vapor-particle split are made at the point of exposure. This is done in the pathway equations in Section 4 using the chemical specific data provided in Section 5.

The values obtained with the unit emission rate are adjusted to chemical specific air concentrations and deposition rates using chemical specific emissions rates. Since the relationship between emissions and air concentrations and deposition rates is linear, the air concentrations and deposition rates resulting from the unit emission rate can be multiplied by the actual emission rate of each chemical to obtain the chemical specific concentrations and deposition rates.

$$\frac{Chemical\ Air\ Concentration}{Chemical\ Emission\ Rate} = \frac{Modeled\ Air\ Concentration}{Unit\ Emission\ Rate\ (1\ g/s)}$$

Since the unit emission rate = 1, this reduces to:

$$Chemical\ Air\ Concentration = Chemical\ Emission\ Rate * Modeled\ Air\ Concentration$$

Similarly, the chemical specific deposition is calculated as follows:

$$Chemical\ Deposition = Chemical\ Emission\ Rate * Modeled\ Deposition\ (wet\&dry\ combined)$$

3.4 Exposure Locations

The locations of the maximum combined wet and dry deposition and the maximum air concentration, as output by the COMPDEP model, are used in the screening analysis as the initial point of departure for all indirect exposures. However, for the subsistence farmer or subsistence fisher scenarios, a less conservative assumption could be made based on local land

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[3] A preprocessor for the precipitation files is being developed and will also be available on SCRAM.

use and water resource information. Such information would be examined in order to determine the actual locations of agricultural fields, pasture lands, and watersheds of interest. One approach would then be to use the maximum combined deposition (wet and dry) from a single receptor located over the field, pasture, or watershed and the maximum air concentration. For the subsistence fisher scenario, a more refined approach would be to locate the actual boundaries of the watershed to calculate the average combined (wet and dry) deposition over the watershed instead of using the maximum combined deposition. These alternative approaches are discussed further in Section 3.5, Receptor Placement.

The locations of the maximum combined deposition (wet and dry) and maximum air concentrations should generally always be used for the residential exposure scenarios unless these are at locations where it is implausible that a residence could be located (e.g., over a lake or a large industrial area). In this case, the highest combined deposition and highest air concentration from locations where a residence could be located should be used. This could be on the shoreline of a lake, on currently vacant land beyond the facility or industrial area, or at the location of a current residence.

Similarly, the location of the maximum air concentration, as output by the COMPDEP model, is used in the screening analysis as the initial point of departure for all direct exposures. Direct inhalation exposures are estimated from the maximum air concentration. For the purpose of characterizing risk, the maximum air concentration is assumed to be collocated with the point of maximum combined deposition. However, as discussed above, for the subsistence farmer or subsistence fisher scenarios, a less conservative assumption could be made based on local land use or water resource information. Such information would be used to determine the actual locations of agricultural fields, pasture lands, and watersheds of interest. In this case, the maximum air concentration from a single receptor located over the field, pasture, or watershed would be used in the screening analysis.

3.5 Receptor Placement

As downloaded from the SCRAM BBS, the COMPDEP model limits the number of receptors to 500. Impacts of emissions are generally higher closer to the source. Due to the need to locate the maximum impact (within the constraints of the model), the receptors are spaced at logarithmic intervals from 100 meters to 10 kilometers from the source.[4]

For the screening analysis, a default polar array of receptors along 16 radials spaced every 22.5° is used in the initial COMPDEP run. The receptors are spaced at distances of 100, 150, 200, 300, 400, 500, 700, 1000, 1500, 2000, 3000, 4000, 5000, 7000, and 10000 meters from the stack. The COMPDEP model run with these receptors provides the maximum air concentration and combined deposition (each from a single receptor) which is used in the screening analysis. The current version of COMPDEP requires that the receptors be input in

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[4] Model results for receptors located closer than 100 meters may not be reliable.

Cartesian coordinates. Table 3.3 lists the Cartesian equivalents of the recommended polar array of receptors.

Site-specific information could be used to identify other receptors which represent the actual locations of agricultural areas or watersheds. If the actual locations of agricultural areas and watersheds are known, the highest values of air concentration and combined deposition from the set of individual receptors that lie within the boundaries of the area would be used in place of the maximum values from the entire array of receptors.

For large watersheds, a second COMPDEP model run could be performed. This run would use a new array of receptors. The new array would cover the area of the watershed of interest only, with receptors placed on a Cartesian grid at 500 meter intervals over the entire area. For the purpose of assessing indirect exposures, the areal average air concentration and areal average combined deposition from all receptors for this new model run would be used rather than the highest values from the set of individual receptors that lie within the watershed boundaries (as from the initial model run). COMPDEP automatically calculates the average "hourly" air concentration across all receptors and the average combined deposition across all receptors.

When local land use information is not available, the original array of receptors could be replaced in a second COMPDEP run by a default watershed. The grid of receptors would be centered on the point of the maximum combined deposition, as determined from the initial model run. For the default watershed, the array of receptors would cover an area of 7000 meters by 7000 meters with the receptors placed on a Cartesian grid at 500 meter intervals.[5] The average "hourly" air concentration across all receptors and the average combined deposition across all receptors, as calculated by the model, would be used rather than the highest values from the set of individual receptors that lie within the watershed boundaries (as from the initial model run).

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[5] The default watershed has an area of 5000 hectares, a value representing the 10th percentile of a national distribution of watershed areas.

Table 3.3 Conversion of Polar Receptor Array to Cartesian Coordinates

Azimuth (°)	Radius (m)	X (m)	Y (m)
0.0	100	0	100
22.5	100	38	92
45.0	100	71	71
67.5	100	92	38
90.0	100	100	0
112.5	100	92	-38
135.0	100	71	-71
157.5	100	38	-92
180.0	100	0	-100
202.5	100	-38	-92
225.0	100	-71	-71
247.5	100	-92	-38
270.0	100	-100	0
292.5	100	-92	38
315.0	100	-71	71
337.5	100	-38	92
0.0	150	0	150
22.5	150	57	139
45.0	150	106	106
67.5	150	139	57
90.0	150	150	0
112.5	150	139	-57
135.0	150	106	-106
157.5	150	57	-139
180.0	150	0	-150
202.5	150	-57	-139
225.0	150	-106	-106
247.5	150	-139	-57
270.0	150	-150	0
292.5	150	-139	57
315.0	150	-106	106
337.5	150	-57	139
0.0	200	0	200
22.5	200	77	185
45.0	200	141	141
67.5	200	185	77
90.0	200	200	0
112.5	200	185	-77
135.0	200	141	-141
157.5	200	77	-185
180.0	200	0	-200
202.5	200	-77	-185
225.0	200	-141	-141
247.5	200	-185	-77
270.0	200	-200	0
292.5	200	-185	77
315.0	200	-141	141
337.5	200	-77	185
0.0	300	0	300
22.5	300	115	277
45.0	300	212	212
67.5	300	277	115
90.0	300	300	0
112.5	300	277	-115
135.0	300	212	-212
157.5	300	115	-277
180.0	300	0	-300
202.5	300	-115	-277

Table 3.3 Conversion of Polar Receptor Array to Cartesian Coordinates

Azimuth	Radius	X	Y	Azimuth	Radius	X	Y
(°)	(m)	(m)	(m)	(°)	(m)	(m)	(m)
225.0	300	-212	-212	157.5	500	191	-462
247.5	300	-277	-115	180.0	500	0	-500
270.0	300	-300	0	202.5	500	-191	-462
292.5	300	-277	115	225.0	500	-354	-354
315.0	300	-212	212	247.5	500	-462	-191
337.5	300	-115	277	270.0	500	-500	0
0.0	400	0	400	292.5	500	-462	191
22.5	400	153	370	315.0	500	-354	354
45.0	400	283	283	337.5	500	-191	462
67.5	400	370	153	0.0	700	0	700
90.0	400	400	0	22.5	700	268	647
112.5	400	370	-153	45.0	700	495	495
135.0	400	283	-283	67.5	700	647	268
157.5	400	153	-370	90.0	700	700	0
180.0	400	0	-400	112.5	700	647	-268
202.5	400	-153	-370	135.0	700	495	-495
225.0	400	-283	-283	157.5	700	268	-647
247.5	400	-370	-153	180.0	700	0	-700
270.0	400	-400	0	202.5	700	-268	-647
292.5	400	-370	153	225.0	700	-495	-495
315.0	400	-283	283	247.5	700	-647	-268
337.5	400	-153	370	270.0	700	-700	0
0.0	500	0	500	292.5	700	-647	268
22.5	500	191	462	315.0	700	-495	495
45.0	500	354	354	337.5	700	-268	647
67.5	500	462	191	0.0	1000	0	1000
90.0	500	500	0	22.5	1000	383	924
112.5	500	462	-191	45.0	1000	707	707
135.0	500	354	-354	67.5	1000	924	383

Table 3.3 Conversion of Polar Receptor Array to Cartesian Coordinates

Azimuth (°)	Radius (m)	X (m)	Y (m)
90.0	1000	1000	0
112.5	1000	924	-383
135.0	1000	707	-707
157.5	1000	383	-924
180.0	1000	0	-1000
202.5	1000	-383	-924
225.0	1000	-707	-707
247.5	1000	-924	-383
270.0	1000	-1000	0
292.5	1000	-924	383
315.0	1000	-707	707
337.5	1000	-383	924
0.0	1500	0	1500
22.5	1500	574	1386
45.0	1500	1061	1061
67.5	1500	1386	574
90.0	1500	1500	0
112.5	1500	1386	-574
135.0	1500	1061	-1061
157.5	1500	574	-1386
180.0	1500	0	-1500
202.5	1500	-574	-1386
225.0	1500	-1061	-1061
247.5	1500	-1386	-574
270.0	1500	-1500	0
292.5	1500	-1386	574
315.0	1500	-1061	1061
337.5	1500	-574	1386
0.0	2000	0	2000
22.5	2000	765	1848
45.0	2000	1414	1414
67.5	2000	1848	765
90.0	2000	2000	0
112.5	2000	1848	-765
135.0	2000	1414	-1414
157.5	2000	765	-1848
180.0	2000	0	-2000
202.5	2000	-765	-1848
225.0	2000	-1414	-1414
247.5	2000	-1848	-765
270.0	2000	-2000	0
292.5	2000	-1848	765
315.0	2000	-1414	1414
337.5	2000	-765	1848
0.0	3000	0	3000
22.5	3000	1148	2772
45.0	3000	2121	2121
67.5	3000	2772	1148
90.0	3000	3000	0
112.5	3000	2772	-1148
135.0	3000	2121	-2121
157.5	3000	1148	-2772
180.0	3000	0	-3000
202.5	3000	-1148	-2772
225.0	3000	-2121	-2121
247.5	3000	-2772	-1148
270.0	3000	-3000	0
292.5	3000	-2772	1148

Table 3.3 Conversion of Polar Receptor Array to Cartesian Coordinates

Azimuth	Radius	X	Y	Azimuth	Radius	X	Y
(°)	(m)	(m)	(m)	(°)	(m)	(m)	(m)
315.0	3000	-2121	2121	247.5	5000	-4619	-1913
337.5	3000	-1148	2772	270.0	5000	-5000	0
0.0	4000	0	4000	292.5	5000	-4619	1913
22.5	4000	1531	3696	315.0	5000	-3536	3536
45.0	4000	2828	2828	337.5	5000	-1913	4619
67.5	4000	3696	1531	0.0	7000	0	7000
90.0	4000	4000	0	22.5	7000	2679	6467
112.5	4000	3696	-1531	45.0	7000	4950	4950
135.0	4000	2828	-2828	67.5	7000	6467	2679
157.5	4000	1531	-3696	90.0	7000	7000	0
180.0	4000	0	-4000	112.5	7000	6467	-2679
202.5	4000	-1531	-3696	135.0	7000	4950	-4950
225.0	4000	-2828	-2828	157.5	7000	2679	-6467
247.5	4000	-3696	-1531	180.0	7000	0	-7000
270.0	4000	-4000	0	202.5	7000	-2679	-6467
292.5	4000	-3696	1531	225.0	7000	-4950	-4950
315.0	4000	-2828	2828	247.5	7000	-6467	-2679
337.5	4000	-1531	3696	270.0	7000	-7000	0
0.0	5000	0	5000	292.5	7000	-6467	2679
22.5	5000	1913	4619	315.0	7000	-4950	4950
45.0	5000	3536	3536	337.5	7000	-2679	6467
67.5	5000	4619	1913	0.0	10000	0	10000
90.0	5000	5000	0	22.5	10000	3827	9239
112.5	5000	4619	-1913	45.0	10000	7071	7071
135.0	5000	3536	-3536	67.5	10000	9239	3827
157.5	5000	1913	-4619	90.0	10000	10000	0
180.0	5000	0	-5000	112.5	10000	9239	-3827
202.5	5000	-1913	-4619	135.0	10000	7071	-7071
225.0	5000	-3536	-3536	157.5	10000	3827	-9239

Table 3.3 Conversion of Polar Receptor Array to Cartesian Coordinates

Azimuth (°)	Radius (m)	X (m)	Y (m)	Azimuth (°)	Radius (m)	X (m)	Y (m)
180.0	10000	0	-10000				
202.5	10000	-3827	-9239				
225.0	10000	-7071	-7071				
247.5	10000	-9239	-3827				
270.0	10000	-10000	0				
292.5	10000	-9239	3827				
315.0	10000	-7071	7071				
337.5	10000	-3827	9239				

3.6 Terrain

Terrain inputs for the source and each receptor are required in areas of complex terrain. For the screening analysis, actual terrain elevations must be used if the terrain rises as high as the top of the stack within about 5 kilometers of the stack. For areas with terrain which remains below the top of the stack, the use of site-specific terrain heights is not essential. In this case flat terrain could be assumed. However, the use of actual terrain heights may be desirable in areas with significant terrain features even though the terrain remains below stack top within 5 kilometers.

Terrain elevation heights can be obtained from U.S. Geologic Survey topographic maps. The appropriate USGS topographic maps should be acquired for the area surrounding the facility in order to evaluate whether or not a terrain adjustment is necessary. Local USGS topographic maps are available from the USGS office located in each State, through local blueprint and map supply shops, or from the USGS Map Distribution Center in Denver, Colorado.

3.7 Determining Watershed Area

The total watershed surface area that is affected by deposition and that drains to the body of water can be quite extensive. Therefore, it is important to consider the hydrology of the watershed itself. Water and sediments in a waterbody may originate from watershed runoff and soils that are (or could be) significantly impacted by combustion emissions as well as watershed runoff and soils that are relatively unaffected. If a combustion source is depositing principally on a land area which feeds a tributary of a large river system, then the assessor should consider what might be termed an "effective" area. An "effective" area will almost always be less than the total area of the watershed. A "watershed" contains all the land area which contributes water to a river system. For large river systems, this area is on the order of thousands of square miles and can include any number of tributaries and smaller streams feeding into the main branch of the river. Each stream and tributary has its own drainage area. If the area which is most strongly impacted by combustion emissions can be ascertained to lie within such a drainage area, then it would be appropriate to assign watershed area based on the drainage area size.

Another important consideration is whether or not the water body in question supports or could support a significant fishery resource. In general, it may be most efficient for the assessor to identify water resources that support subsistence or recreational fishing and then to focus on the smallest drainage area that feeds those water resources which is closest to the facility and could itself support fishing activities.

Another consideration for determining watershed area is the location of the facility with respect to the point where fish are caught for consumption. If this point is far upstream in the watershed relative to the location of the facility, there may be little reason to think that sediments or water near where fish are caught are significantly impacted by the combustion source. However, if this point is downstream from the facility, then sediment and water quality near where fish are caught could be affected. In this instance, points further downstream from where fish are caught (e.g., at the bottom of the watershed) may not be of interest. If this is the case, land draining into these downstream areas should not be part of the "effective" drainage area.

For a standing waterbody such as a lake or pond, the watershed area should be the area around the lake or pond which contributes runoff and sediments to the waterbody and, as in the above discussion on river systems, a part of the land area contributing runoff and sediments to streams or rivers which may feed the lake or pond.

Local topographic maps, land use information, and State game and fish commissions may be of help in determining the appropriate size and location of the watershed.

Due to the inherent limitations of the COMPDEP model, receptors should not be placed beyond 50 kilometers from the stack. Therefore, watershed areas that extend beyond 50 kilometers from the facility need not be considered in the screening analysis.

3.8 Surface Roughness

The surface roughness is a reflection of the land use over the region. Surface roughness measures the variations in the height of the individual surface elements. The value is used to characterize the turbulence which results in deposition at the ground surface. Table 3.4 lists the roughness heights which can be used as input to the COMPDEP model. These values are based on the general land use in the vicinity of the stack (or within the area over which deposition is a concern).

Table 3.4 Typical Surface Roughness Lengths for Various Land Use Types

Land Use	Typical Roughness Length	
	(centimeters)	(meters)
Urban - Commercial/Industrial	200	2.0
Common residential - single family dwellings	20	0.20
Compact residential - multi-family dwelling	50	0.5
Metropolitan natural (parks, golf courses)	15	0.15
Agricultural - rural	20	0.20
Semi-rural	20	0.20
Undeveloped, wasteland	5	0.05
Forest	100	1.0
Bottomland agricultural	15	0.15
All values from U.S. EPA, 1993a.		

4. INDIRECT EXPOSURE PATHWAY EQUATIONS

This section presents the equations that are used in the screening analysis to calculate media and food concentrations of contaminants for the indirect exposure pathways. Values are provided for parameters that are not chemical or site-specific. The chemical-specific parameter values are presented in table format in Section 5.

The individual equations are organized into five overall pathway groupings that are related to human ingestion of media and food. These are as follows: 1) soil ingestion; 2) consumption of above-ground vegetables; 3) consumption of root vegetables; 4) consumption of beef and milk; and 5) fish consumption. Each group is discussed in a separate section as indicated in the text box. In each section, all equations for calculating contaminant concentrations for the individual pathways in the group are provided in table format. The introduction to each section provides a brief discussion of what the equations do, which aspects of the calculations have been omitted from the screening analysis, and which exposure scenarios the group of calculations applies to. The introduction also identifies which two input parameters that have been set to high end values for that pathway group. Guidance is also provided on setting site-specific input parameters where site-specific values are needed.

Section 4.1	**Soil Ingestion**
Section 4.2	**Consumption of Above-ground Vegetables**
Section 4.3	**Consumption of Root Vegetables**
Section 4.4	**Consumption of Beef and Milk**
Section 4.5	**Consumption of Fish**

Tables 4.0.1 and 4.0.2 are provided for easy reference. Table 4.0.1 identifies which equations are used for each exposure scenario. Table 4.0.2 identifies which equations are used for each chemical.

Each equation is presented in table format. The tables show the equations, identify the exposure scenarios and constituents for which the equations are to be used, list all input parameters, and provide default values as appropriate. The default value column of the tables may contain one of the following designations instead of (or in addition to) a default value:

- **shaded, no value**: this signifies that this row of the table describes either the parameter being calculated by the given equation or a units conversion constant in the equation.
- **modeled (see Sec. 3)**: this indicates a deposition rate or air concentration, as determined by COMPDEP model, as described in Section 3.
- **calculated (see Table 4.x.x)**: this indicates that an equation is given for calculating the parameter in the indicated table.

- **site-specific:** this indicates that the parameter is site-specific and that no default value is considered appropriate.

- **High end: value:** this indicates that the parameter is one of two parameters that have been set to high end values for the pathway grouping.

For parameters that are marked site-specific, the user must determine an appropriate site-specific value. Guidance is provided in the introductory sections to each pathway grouping on setting values for site-specific parameters.

If site-specific data are used instead of the default value for setting a value for a parameter that is indicated in the tables as being set to a high end value, a high end site-specific value should be used. This may be a 90th percentile value or a 10th percentile value, depending on the parameter. The appropriate percentile is indicated in the introduction to each section.

Table 4.0.1. Summary of Screening Equation Use by Scenario

Table	Pathway Component	Scenario			
		Subsistence Farmer	Subsistence Fisher	Adult Resident	Child Resident
Soil Ingestion Pathway					
4.1.1	Deposition to Soil	✓	✓	✓	✓
4.1.2	Soil Loss Constant	✓	✓	✓	✓
Above-ground Vegetable Pathway					
4.2.1	Above-ground Vegetable Concentration from Deposition	✓	✓	✓	✓
4.2.2	Above-ground Vegetable Concentration from Direct Air-to-Plant Transfer	✓	✓	✓	✓
Root Vegetable Pathway					
4.3.1	Deposition to Soil	✓	✓	✓	✓
4.3.2	Root Vegetable Concentration from Root Uptake	✓	✓	✓	✓
Beef and Milk Pathways					
4.4.1	Deposition to Soil	✓			
4.4.2	Above-ground Plant Concentration from Deposition	✓			
4.4.3	Above-ground Plant Concentration from Direct Air-to-Plant Transfer	✓			
4.4.4	Beef Concentration from Ingestion of Above-ground Plants and Soil	✓			
4.4.5	Milk Concentration from Ingestion of Above-ground Plants and Soil	✓			

Table 4.0.1. Summary of Screening Equation Use by Scenario

Table	Pathway Component	Scenario			
		Subsistence Farmer	Subsistence Fisher	Adult Resident	Child Resident
Fish Pathway					
4.5.1	Deposition to Watershed Soil		✓		
4.5.2	Waterbody Load		✓		
4.5.3	Deposition to Waterbody		✓		
4.5.4	Impervious Runoff Load		✓		
4.5.5	Pervious Runoff Load		✓		
4.5.6	Erosion Load		✓		
4.5.7	Universal Soil Loss Equation		✓		
4.5.8	Sediment Delivery Ratio		✓		
4.5.9	Waterbody Concentration		✓		
4.5.10	Fraction in Water Column and Sediment		✓		
4.5.11	Total Water Column Concentration		✓		
4.5.12	Dissolved Water Concentration		✓		
4.5.13	Bed Sediment Concentration		✓		
4.5.14	Fish Concentration from Dissolved Water Concentration		✓		
4.5.15	Fish Concentration from Total Water Column Concentration		✓		
4.5.16	Fish Concentration from Bed Sediment Concentration		✓		

Table 4.0.2. Summary of Screening Equation Use by Chemical

Table	Pathway Component	Arsenic	Beryllium	Benzo(a) pyrene	Bis (2-ethyl hexyl) phthalate	1,3-Dinitro benzene	2,4-Dinitro toluene	2,6-Dinitro toluene	Di(n)octyl phthalate
Soil Ingestion Pathway									
4.1.1	Deposition to Soil	✓	✓	✓	✓	✓	✓	✓	✓
4.1.2	Soil Loss Constant								
Above-ground Vegetable Pathway									
4.2.1	Above-ground Vegetable Concentration from Deposition	✓	✓	✓	✓	✓	✓	✓	✓
4.2.2	Above-ground Vegetable Concentration from Direct Air-to-Plant Transfer			✓	✓	✓	✓	✓	✓
Root Vegetable Pathway									
4.3.1	Deposition to Soil	✓	✓	✓	✓	✓	✓	✓	✓
4.3.2	Root Vegetable Concentration from Root Uptake	✓	✓	✓	✓	✓	✓	✓	✓
Beef and Milk Pathways									
4.4.1	Deposition to Soil	✓	✓	✓		✓	✓	✓	
4.4.2	Above-ground Plant Concentration from Deposition	✓	✓	✓		✓	✓	✓	
4.4.3	Above-ground Plant Concentration from Direct Air-to-Plant Transfer			✓		✓	✓	✓	
4.4.4	Beef Concentration from Ingestion of Above-ground Plants and Soil	✓	✓	✓		✓	✓	✓	
4.4.5	Milk Concentration from Ingestion of Above-ground Plants and Soil	✓	✓	✓		✓	✓	✓	

Table 4.0.2: Summary of Screening Equation Use by Chemical

Table	Pathway Component	Arsenic	Beryllium	Benzo(a) pyrene	Bis (2-ethyl hexyl) phthalate	1,3-Dinitro benzene	2,4-Dinitro toluene	2,6-Dinitro toluene	Di(n)octyl phthalate
Fish Pathway									
4.5.1	Deposition to Watershed Soil	✓	✓	✓	✓		✓	✓	✓
4.5.2	Waterbody Load	✓	✓	✓	✓	✓	✓	✓	✓
4.5.3	Deposition to Waterbody					✓			
4.5.4	Impervious Runoff Load	✓	✓			✓	✓	✓	
4.5.5	Pervious Runoff Load	✓	✓				✓	✓	
4.5.6	Erosion Load			✓	✓				✓
4.5.7	Universal Soil Loss Equation			✓	✓				✓
4.5.8	Sediment Delivery Ratio			✓	✓				✓
4.5.9	Waterbody Concentration	✓	✓	✓	✓	✓	✓	✓	✓
4.5.10	Fraction in Water Column and Sediment	✓	✓	✓	✓	✓	✓	✓	✓
4.5.11	Total Water Column Concentration			✓	✓				✓
4.5.12	Dissolved Water Concentration	✓	✓			✓	✓	✓	
4.5.13	Bed Sediment Concentration								
4.5.14	Fish Concentration from Dissolved Water Concentration	✓	✓			✓	✓	✓	
4.5.15	Fish Concentration from Total Water Column Concentration			✓	✓				✓
4.5.16	Fish Concentration from Bed Sediment Concentration								

Table 4.0.2. Summary of Screening Equation Use by Chemical

Table	Pathway Component	Hexa chloro benzene	Lead	Mercury	Nitro benzene	total PCBs	Penta chloronitro benzene	Penta chloro phenol	2,3,7,8-TCDDioxin
Soil Ingestion Pathway									
4.1.1	Deposition to Soil	✓	✓	✓	✓	✓	✓	✓	✓
4.1.2	Soil Loss Constant								✓
Above-ground Vegetable Pathway									
4.2.1	Above-ground Vegetable Concentration from Deposition	✓		✓	✓	✓	✓	✓	✓
4.2.2	Above-ground Vegetable Concentration from Direct Air-to-Plant Transfer	✓		✓	✓	✓	✓	✓	✓
Root Vegetable Pathway									
4.3.1	Deposition to Soil	✓		✓	✓	✓	✓	✓	✓
4.3.2	Root Vegetable Concentration from Root Uptake	✓		✓	✓	✓	✓	✓	✓
Beef and Milk Pathways									
4.4.1	Deposition to Soil	✓		✓	✓	✓	✓	✓	✓
4.4.2	Above-ground Plant Concentration from Deposition	✓		✓	✓	✓	✓	✓	✓
4.4.3	Above-ground Plant Concentration from Direct Air-to-Plant Transfer	✓		✓	✓	✓	✓	✓	✓
4.4.4	Beef Concentration from Ingestion of Above-ground Plants and Soil	✓		✓	✓	✓	✓	✓	✓
4.4.5	Milk Concentration from Ingestion of Above-ground Plants and Soil	✓		✓	✓	✓	✓	✓	✓

Table 4.0.2. Summary of Screening Equation Use by Chemical

Table	Pathway Component	Hexa chloro benzene	Lead	Mercury	Nitro benzene	total PCBs	Penta chloronitro benzene	Penta chloro phenol	2,3,7,8-TCDDioxin
Fish Pathway									
4.5.1	Deposition to Watershed Soil				✓	✓			✓
4.5.2	Waterbody Load	✓		✓	✓	✓	✓		✓
4.5.3	Deposition to Waterbody	✓		✓			✓		
4.5.4	Impervious Runoff Load	✓		✓	✓		✓		
4.5.5	Pervious Runoff Load				✓				
4.5.6	Erosion Load					✓			✓
4.5.7	Universal Soil Loss Equation					✓			✓
4.5.8	Sediment Delivery Ratio					✓			✓
4.5.9	Waterbody Concentration	✓		✓	✓	✓	✓		✓
4.5.10	Fraction in Water Column and Sediment	✓		✓	✓	✓	✓		✓
4.5.11	Total Water Column Concentration	✓		✓					
4.5.12	Dissolved Water Concentration				✓		✓		
4.5.13	Bed Sediment Concentration					✓			✓
4.5.14	Fish Concentration from Dissolved Water Concentration				✓		✓		
4.5.15	Fish Concentration from Total Water Column Concentration	✓		✓					
4.5.16	Fish Concentration from Bed Sediment Concentration					✓			✓

4.1 Soil Ingestion

The equations in this section calculate the soil concentration resulting from deposition of contaminants onto soils at the location of maximum combined (wet and dry) deposition (or an alternative location, as discussed in Section 3.4, Exposure Locations). Soil contamination by diffusion of vapors from air has been omitted; instead, for the screening analysis vapors are treated in the COMPDEP model as particles for the purpose of estimating dry and wet deposition. The calculation of soil concentration includes a loss term which can account for loss of contaminant from the soil after deposition by several mechanisms, including leaching, erosion, runoff, degradation, and volatilization. These loss mechanisms would all lower the soil concentration associated with a specific deposition rate. For the screening analysis, the loss terms for leaching, erosion, runoff, and volatilization have all been set to zero. This will result in a conservative estimate of soil concentration. The degradation term is chemical-specific. However, the degradation term is also set to zero for all contaminants except dioxin-like compounds. Note that the elimination of the loss terms may be inappropriate for certain chemicals for which the screening procedure is not intended (e.g., volatile organic compounds).

The soil ingestion pathway is used for all exposure scenarios.

The two high end parameters for soil ingestion are the mixing depth (Z) and the soil bulk density (BD). Both mixing depth and soil bulk density should be set to 10th percentile (or low) values.

The only site-specific parameter in this pathway is total time of deposition (Tc). This should be set to the expected lifetime of the combustion source (e.g., 30 years).

Table 4.1.1. Soil Concentration Due to Deposition

Exposure Scenarios

All

Chemicals

Arsenic
Beryllium
Benzo(a)pyrene toxicity equivalents
Bis (2-ethylhexyl) phthalate
1,3-Dinitro benzene
2,4-Dinitro toluene
2,6-Dinitro toluene
Di(n)octyl phthalate
Hexachlorobenzene
Lead
Mercury
Nitrobenzene
total PCBs
Pentachloronitrobenzene
Pentachlorophenol
2,3,7,8-TCDDioxin toxicity equivalents

Equation

2,3,7,8-TCDDioxin only:

$$Sc = \frac{Dyd + Dyw}{Z \cdot BD \cdot ks} \cdot [1.0 - exp(-ks \cdot Tc)] \cdot 100$$

All other chemicals:

$$Sc = \frac{Dyd + Dyw}{Z \cdot BD} \cdot Tc \cdot 100$$

Parameter	Definition	Default Value
Sc	Soil concentration of pollutant after total time period of deposition (mg/kg)	
Dyd	Yearly dry deposition rate of pollutant ($g/m^2/yr$)	modeled (see Section 3)
Dyw	Yearly wet deposition rate of pollutant ($g/m^2/yr$)	modeled (see Section 3)
ks	Soil loss constant (yr^{-1})	calculated (see Table 4.1.2)
Tc	Total time period over which deposition occurs (yrs)	site-specific
100	Units conversion factor ($[mg\text{-}m^2]/[kg\text{-}cm^2]$)	
Z	Soil mixing depth (cm)	High end: 1
BD	Soil bulk density (g/cm^3)	High end: 1.2

Description

These equations calculate soil concentration as a result of wet and dry deposition onto soil. Contaminants are assumed to be incorporated only to a finite depth (the mixing depth, Z). The first equation should be used when the soil loss term, ks, is not zero; this equation is used only for 2,3,7,8-TCDDioxin toxicity equivalents. The second equation should be used when ks is zero (for all other chemicals).

Table 4.1.2. Soil Loss Constant

Exposure Scenarios
All
Chemicals
2,3,7,8-TCDDioxin toxicity equivalents
Equation

$$ks = ksl + kse + ksr + ksg + ksv$$

Parameter	Definition	Default Value
ks	soil loss constant due to all processes (yr^{-1})	
ksl	loss constant due to leaching (yr^{-1})	0
kse	loss constant due to soil erosion (yr^{-1})	0
ksr	loss constant due to surface runoff (yr^{-1})	0
ksg	loss constant due to degradation (yr^{-1})	chemical-specific (see Section 5)
ksv	loss constant due to volatilization (yr^{-1})	0

Description

This equation calculates the soil loss constant, which accounts for the loss of contaminant from soil by several mechanisms. The loss terms for all mechanisms except degradation are assumed to be zero.

4.2 Consumption of Above-ground Vegetables

The equations in this section calculate contaminant concentrations in above-ground vegetables that are eaten by humans.

Above-ground vegetables may be contaminated by combustion emissions through several mechanisms, including direct deposition of contaminants onto the plant, direct uptake of vapor phase contaminants, and root uptake of contaminants deposited on the soil. For the screening analysis, root uptake is omitted for above-ground vegetation. Root uptake is typically a much less important mechanism than direct deposition to the aerial parts of plants. Direct uptake of vapor phase contaminant is included, as this can be significant for some chemicals. Direct deposition of particle phase contaminants on the plant is calculated at the location of maximum combined (wet and dry) deposition (or an alternative location, as discussed in Section 3.4, Exposure Locations). Direct uptake of vapor phase contaminants is calculated at the location of maximum air concentration (or an alternative location, as discussed in Section 3.4).

Because direct uptake of vapor phase contaminants is a form of dry deposition, to insure conservation of mass the dry deposition rate calculated by the COMPDEP model (Dyd), which for the screening analysis is used to represent dry deposition of emissions in both the particle and vapor phases, is adjusted using a factor that represents the fraction of the chemical in the particle phase. Similarly, the air concentration calculated by the COMPDEP model, which represents the total concentration of both airborne particles and vapors, is adjusted using a factor that represents the fraction of the chemical in the vapor phase. The fraction in the vapor phase (Fv) is chemical-specific. The fraction in the particle phase (1 - Fv) is calculated from the fraction in the vapor phase.

The above-ground vegetable pathway is used for all exposure scenarios.

The two high end parameters for consumption of above-ground vegetables are the plant surface loss coefficient (kp) and the crop yield (Yp). The plant surface loss coefficient should be set to a 10th percentile (or low) value. Site-specific values of kp may be estimated by estimating the length of time between rainfalls and converting that to yr^{-1} as follows:

$$kp = \frac{\ln 2}{t_{rain}/365}$$

where:

t_{rain} = time between rainfalls (days)

The time between rainfalls should represent a 90th percentile value, or longer than the average value. The crop yield (Yp) should be set to a 10th percentile (or low) value.

The only site-specific parameter in this pathway is total time of deposition (Tc). This should be set to the expected lifetime of the combustion source (e.g., 30 years).

Table 4.2.1. Above-ground Vegetable Concentration Due to Direct Deposition

Exposure Scenarios

All

Chemicals

Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis (2-ethylhexyl) phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene Di(n)octyl phthalate	Hexachlorobenzene Mercury Nitrobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$Pd = \frac{1000 \cdot [(1.0 - Fv) \cdot Dyd + (Fw \cdot Dyw)] \cdot Rp \cdot [(1.0 - exp(-kp \cdot Tp)]}{Yp \cdot kp}$$

Parameter	Definition	Default Value
Pd	Concentration in plant due to direct deposition (mg/kg)	
1000	Units conversion factor (mg/g)	
Dyd	Yearly dry deposition rate ($g/m^2/yr$)	modeled (see Section 3)
Fw	Fraction of wet deposition that adheres to plant (dimensionless)	chemical-specific (see Section 5)
Fv	Fraction of air concentration in vapor phase (dimensionless)	chemical-specific (see Section 5)
Dyw	Yearly wet deposition rate ($g/m^2/yr$)	modeled (see Section 3)
Rp	Interception fraction of edible portion of plant (dimensionless)	0.3
kp	Plant surface loss coefficient (yr^{-1})	High end: 18
Tp	Length of plant exposure to deposition of edible portion of plant, per harvest (yrs)	0.16
Yp	Yield or standing crop biomass of the edible portion of the plant ($kg\ DW/m^2$)	High end: 0.09

Description

This equation calculates the contaminant concentration in above-ground vegetation due to wet and dry deposition of contaminant on the plant surface.

Table 4.2.2. Above-ground Vegetable Concentration Due to Air-to-Plant Transfer

Exposure Scenarios

All

Chemicals

Benzo(a)pyrene toxicity equivalents
Bis (2-ethylhexyl) phthalate
1,3-Dinitro benzene
2,4-Dinitro toluene
2,6-Dinitro toluene
Di(n)octyl phthalate

Hexachlorobenzene
Mercury
Nitrobenzene
total PCBs
Pentachloronitrobenzene
Pentachlorophenol
2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$Pv = \frac{(Fv \cdot Cy) \cdot Bv}{\rho_a}$$

Parameter	Definition	Default Value
Pv	Concentration of pollutant in the plant due to air-to-plant transfer (mg/kg)	
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	chemical-specific (see Section 5)
Cy	Concentration of pollutant in air due to direct emissions (μg/m^3)	modeled (see Section 3)
Bv	Air-to-plant biotransfer factor ([mg pollutant/kg plant tissue DW]/[μg pollutant/g air])	chemical-specific (see Section 5)
ρ_a	Density of air (g/m^3)	1.2×10^3

Description

This equation calculates the contaminant concentration in above-ground vegetation due to direct uptake of vapor phase contaminants into the plant leaves.

4.3 Consumption of Root Vegetables

The equations in this section calculate contaminant concentrations in root vegetables. Root vegetables may be contaminated by combustion emissions through root uptake of contaminants deposited on the soil. Direct deposition and vapor phase uptake are not important for root vegetables, as none of the edible portion is above the ground.

First, the soil concentration is calculated from the rate of deposition of contaminants onto soils at the location of maximum combined (wet and dry) deposition (or an alternative location, as discussed in Section 3.4, Exposure Locations). Soil contamination by diffusion of vapors from air has been omitted; instead, for the screening analysis vapors are treated in the COMPDEP model as particles for the purpose of estimating dry and wet deposition. The calculation of soil concentration includes a loss term which can account for loss of contaminant from the soil after deposition by several mechanisms, including leaching, erosion, runoff, degradation, and volatilization. These loss mechanisms would all lower the soil concentration associated with a specific deposition rate. For the screening analysis, the loss terms for leaching, erosion, runoff, and volatilization have all been set to zero. This will result in a conservative estimate of soil concentration. The degradation term is chemical-specific. However, the degradation term is also set to zero for all contaminants except dioxin-like compounds. Note that the elimination of the loss terms may be inappropriate for certain chemicals for which the screening procedure is not intended (e.g., volatile organic compounds).

Uptake of contaminants from the soil pore water into the root of the plant is then calculated from the soil concentration using the soil-water partition coefficient and a root concentration factor (RCF).

The consumption of root vegetables pathway is used for all exposure scenarios.

The two high end parameters for consumption of root vegetables are mixing depth (Z) and soil bulk density (BD). Both mixing depth and soil bulk density should be set to 10th percentile (or low) values.

The only site-specific parameter in this pathway is total time of deposition (Tc). This should be set to the expected lifetime of the combustion source (e.g., 30 years).

Table 4.3.1. Soil Concentration Due to Deposition

Exposure Scenarios

All

Chemicals

Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis (2-ethylhexyl) phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene Di(n)octyl phthalate	Hexachlorobenzene Mercury Nitrobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

2,3,7,8-TCDDioxin only:

$$Sc = \frac{Dyd + Dyw}{Z \cdot BD \cdot ks} \cdot [1.0 - exp(-ks \cdot Tc)] \cdot 100$$

All other chemicals:

$$Sc = \frac{Dyd + Dyw}{Z \cdot BD} \cdot Tc \cdot 100$$

Parameter	Definition	Default Value
Sc	Soil concentration of pollutant after total time period of deposition (mg/kg)	
Dyd	Yearly dry deposition rate of pollutant ($g/m^2/yr$)	modeled (see Section 3)
Dyw	Yearly wet deposition rate of pollutant ($g/m^2/yr$)	modeled (see Section 3)
ks	Soil loss constant (yr^{-1})	calculated (see Table 4.1.2)
Tc	Total time period over which deposition occurs (yrs)	site-specific
100	Units conversion factor ($[mg\text{-}m^2]/[kg\text{-}cm^2]$)	
Z	Soil mixing depth (cm)	High end: 1
BD	Soil bulk density (g/cm^3)	High end: 1.2

Description

These equations calculate soil concentration as a result of wet and dry deposition onto soil. Contaminants are assumed to be incorporated only to a finite depth (the mixing depth, Z). The first equation should be used when the soil loss term, ks, is not zero; this equation is used only for 2,3,7,8-TCDDioxin toxicity equivalents. The second equation should be used when ks is zero (for all other chemicals).

Table 4.3.2. Root Vegetable Concentration Due to Root Uptake

Exposure Scenarios	
All	
Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis (2-ethylhexyl) phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene Di(n)octyl phthalate	Hexachlorobenzene Mercury Nitrobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$Pr_{bg} = \frac{Sc \cdot RCF}{Kd_s}$$

Parameter	Definition	Default Value
Pr_{bg}	Concentration of pollutant in below ground plant parts due to root uptake (mg/kg)	
Sc	Soil concentration of pollutant (mg/kg)	calculated (see Table 4.3.1)
Kd_s	Soil-water partition coefficient (mL/g)	chemical-specific (see Section 5)
RCF	Ratio of concentration in roots to concentration in soil pore water ([mg pollutant/kg plant tissue FW]/[μg pollutant/mL pore water])	chemical-specific (see Section 5)

Description

This equation calculates the contaminant concentration in root vegetables due to uptake from the soil water.

4.4 Consumption of Beef and Milk

The equations in this section calculate contaminant concentrations in beef tissue and milk due to ingestion of contaminated forage and soil by beef and dairy cattle. Equations could be provided or modified to reflect consumption of contaminated grain. However, ingestion of grain is a less important pathway than ingestion of forage. The default values for ingestion of above-ground plants are for forage consumption only.

Forage may be contaminated by combustion emissions through several mechanisms, including direct deposition of contaminants onto the plant, direct uptake of vapor phase contaminants, and root uptake of contaminants deposited on the soil. For the screening analysis, root uptake is omitted. Root uptake is typically a much less important mechanism than direct deposition to the aerial parts of plants. Direct uptake of vapor phase contaminant is included, as this can be significant for some chemicals. Direct deposition of particle phase contaminants on the plant is calculated at the location of maximum combined (wet and dry) deposition (or an alternative location, as discussed in Section 3.4, Exposure Locations). Direct uptake of vapor phase contaminants is calculated at the location of maximum air concentration (or an alternative location, as discussed in Section 3.4, Exposure Locations).

Because direct uptake of vapor phase contaminants is a form of dry deposition, to insure conservation of mass the dry deposition rate calculated by the COMPDEP model (Dyd), which for the screening analysis is used to represent dry deposition of emissions in both the particle and vapor phases, is adjusted using a factor that represents the fraction of the chemical in the particle phase. Similarly, the air concentration calculated by the COMPDEP model, which represents the total concentration of both airborne particles and vapors, is adjusted using a factor that represents the fraction of the chemical in the vapor phase. The fraction in the vapor phase (Fv) is chemical-specific. The fraction in the particle phase (1 - Fv) is calculated from the fraction in the vapor phase.

It is also necessary to calculate the soil concentration resulting from deposition of contaminants onto soils at the location of maximum combined (wet and dry) deposition (or an alternative location, as discussed in Section 3.4, Exposure Locations). Soil contamination by diffusion of vapors from air has been omitted; instead, for the screening analysis vapors are treated in the COMPDEP model as particles for the purpose of estimating dry and wet deposition. The calculation of soil concentration includes a loss term which can account for loss of contaminant from the soil after deposition by several mechanisms, including leaching, erosion, runoff, degradation, and volatilization. These loss mechanisms would all lower the soil concentration associated with a specific deposition rate. For the screening analysis, the loss terms for leaching, erosion, runoff, and volatilization have all been set to zero. This will result in a conservative estimate of soil concentration. The degradation term is chemical-specific. However, the degradation term is also set to zero for all contaminants except dioxin-like compounds. Note that the elimination of the loss terms may be inappropriate for certain chemicals for which the screening procedure is not intended (e.g., volatile organic compounds).

The consumption of beef and milk pathway is used only for the subsistence farmer exposure scenario.

The two high end parameters for the consumption of beef and milk are the soil mixing depth (Z) and the crop yield (Yp). The soil mixing depth should be set to a 10th percentile (or low) value. The crop yield (Yp) should also be set to a 10th percentile (or low) value.

The only site-specific parameter in this pathway is total time of deposition (Tc). This should be set to the expected lifetime of the combustion source (e.g., 30 years).

Table 4.4.1. Soil Concentration Due to Deposition

Exposure Scenarios

Subsistence Farmer

Chemicals

- Arsenic
- Beryllium
- Benzo(a)pyrene toxicity equivalents
- 1,3-Dinitro benzene
- 2,4-Dinitro toluene
- 2,6-Dinitro toluene
- Hexachlorobenzene
- Mercury
- Nitrobenzene
- total PCBs
- Pentachloronitrobenzene
- Pentachlorophenol
- 2,3,7,8-TCDDioxin toxicity equivalents

Equation

2,3,7,8-TCDDioxin only:

$$Sc = \frac{Dyd + Dyw}{Z \cdot BD \cdot ks} \cdot [1.0 - exp(-ks \cdot Tc)] \cdot 100$$

All other chemicals:

$$Sc = \frac{Dyd + Dyw}{Z \cdot BD} \cdot Tc \cdot 100$$

Parameter	Definition	Default Value
Sc	Soil concentration of pollutant after total time period of deposition (mg/kg)	
Dyd	Yearly dry deposition rate of pollutant ($g/m^2/yr$)	modeled (see Section 3)
Dyw	Yearly wet deposition rate of pollutant ($g/m^2/yr$)	modeled (see Section 3)
ks	Soil loss constant (yr^{-1})	calculated (see Table 4.1.2)
Tc	Total time period over which deposition occurs (yrs)	site-specific
100	Units conversion factor ($[mg\text{-}m^2]/[kg\text{-}cm^2]$)	
Z	Soil mixing depth (cm)	High end: 1
BD	Soil bulk density (g/cm^3)	1.5

Description

These equations calculate soil concentration as a result of wet and dry deposition onto soil. Contaminants are assumed to be incorporated only to a finite depth (the mixing depth, Z). The first equation should be used when the soil loss term, ks, is not zero; this equation is used only for 2,3,7,8-TCDDioxin toxicity equivalents. The second equation should be used when ks is zero (for all other chemicals).

Table 4.4.2. Above-ground Plant Concentration Due to Direct Deposition

Exposure Scenarios

Subsistence Farmer

Chemicals

- Arsenic
- Beryllium
- Benzo(a)pyrene toxicity equivalents
- 1,3-Dinitro benzene
- 2,4-Dinitro toluene
- 2,6-Dinitro toluene
- Hexachlorobenzene
- Mercury
- Nitrobenzene
- total PCBs
- Pentachloronitrobenzene
- Pentachlorophenol
- 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$Pd = \frac{1000 \cdot [(1 - Fv) \cdot Dyd + (Fw \cdot Dyw)] \cdot Rp \cdot [(1.0 - \exp(-kp \cdot Tp)]}{Yp \cdot kp}$$

Parameter	Definition	Default Value
Pd	Concentration in plant due to direct deposition (mg/kg)	
1000	Units conversion factor (mg/g)	
Dyd	Yearly dry deposition rate ($g/m^2/yr$)	modeled (see Section 3)
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	chemical-specific (see Section 5)
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	chemical-specific (see Section 5)
Dyw	Yearly wet deposition rate ($g/m^2/yr$)	modeled (see Section 3)
Rp	Interception fraction of the edible portion of the plant tissue (dimensionless)	0.44
kp	Plant surface loss coefficient (yr^{-1})	18
Tp	Length of the plant's exposure to deposition per harvest of the edible portion of the plant (yrs)	0.12
Yp	Yield or standing crop biomass of the edible portion of the plant ($kg\ DW/m^2$)	High end: 0.02

Description

This equation calculates the contaminant concentration in above-ground vegetation due to wet and dry deposition of contaminant on the plant surface.

Table 4.4.3. Above-ground Plant Concentration Due to Air-to-Plant Transfer

Exposure Scenarios

Subsistence Farmer

Chemicals

Benzo(a)pyrene toxicity equivalents
1,3-Dinitro benzene
2,4-Dinitro toluene
2,6-Dinitro toluene
Hexachlorobenzene
Mercury
Nitrobenzene
total PCBs
Pentachloronitrobenzene
Pentachlorophenol
2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$Pv = \frac{(Fv \cdot Cy) \cdot Bv}{\rho_a}$$

Parameter	Definition	Default Value
Pv	Concentration of pollutant in the plant due to air-to-plant transfer (mg/kg)	
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	chemical-specific (see Section 5)
Cy	Concentration of pollutant in air due to direct emissions (μg pollutant/m^3)	modeled (see Section 3)
Bv	Air-to-plant biotransfer factor ([mg pollutant/kg plant tissue DW]/[μg [pollutant/g air])	chemical-specific (see Section 5)
ρ_a	Density of air (g/m^3)	1.2×10^3

Description

This equation calculates the contaminant concentration in above-ground vegetation due to direct uptake of vapor phase contaminants into the plant leaves.

Table 4.4.4. Beef Concentration Due to Plant and Soil Ingestion

Exposure Scenarios	
Subsistence Farmer	
Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene Hexachlorobenzene	Mercury Nitrobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$A_{beef} = (F \cdot Qp \cdot P + Qs \cdot Sc) \cdot Ba_{beef}$$

Parameter	Definition	Default Value
A_{beef}	Concentration of pollutant in beef (mg/kg)	
F	Fraction of plant grown on contaminated soil and eaten by the animal (dimensionless)	1
Qp	Quantity of plant eaten by the animal each day (kg plant tissue DW/day)	8.8
P	Total concentration of pollutant in the plant eaten by the animal (mg/kg) = Pd + Pv	calculated (see Tables 4.4.2, 4.4.3)
Qs	Quantity of soil eaten by the animal (kg soil/day)	0.4
Sc	Soil concentration (mg/kg)	calculated (see Table 4.4.1)
Ba_{beef}	Biotransfer factor for beef (d/kg)	chemical-specific (see Section 5)

Description

This equation calculates the concentration of contaminant in beef from ingestion of forage and soil.

Table 4.4.5. Milk Concentration Due to Plant and Soil Ingestion

Exposure Scenarios	
Subsistence Farmer	
Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene Hexachlorobenzene	Mercury Nitrobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$A_{milk} = (F \cdot Qp \cdot P + Qs \cdot Sc) \cdot Ba_{milk}$$

Parameter	Definition	Default Value
A_{milk}	Concentration of pollutant in milk (mg/kg)	
F	Fraction of plant grown on contaminated soil and eaten by the animal (dimensionless)	1
Qp	Quantity of plant eaten by the animal each day (kg plant tissue DW/day)	11
P	Total concentration of pollutant in the plant eaten by the animal (mg/kg) = Pd + Pv	calculated (see Tables 4.4.2, 4.4.3)
Qs	Quantity of soil eaten by the animal (kg soil/day)	1.6
Sc	Soil concentration (mg/kg)	calculated (see Table 4.4.1)
Ba_{milk}	Biotransfer factor for milk (day/kg)	chemical-specific (see Section 5)

Description

This equation calculates the concentration of contaminant in milk from ingestion of forage and soil.

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4.5 Consumption of Fish

The equations in this section calculate contaminant concentrations in fish from contaminant concentrations in the waterbody, either dissolved or total water column concentrations or sediment concentrations. This is done in several steps.

The first step is to calculate the soil concentration resulting from deposition of contaminants onto soils at the location of maximum combined (wet and dry) deposition (or an alternative location, as discussed in Section 3.4, Exposure Locations). Soil contamination by diffusion of vapors from air has been omitted; instead, for the screening analysis vapors are treated in the COMPDEP model as particles for the purpose of estimating dry and wet deposition. The calculation of soil concentration includes a loss term which can account for loss of contaminant from the soil after deposition by several mechanisms, including leaching, erosion, runoff, degradation, and volatilization. These loss mechanisms would all lower the soil concentration associated with a specific deposition rate. For the screening analysis, the loss terms for leaching, erosion, runoff, and volatilization have all been set to zero. This will result in a conservative estimate of soil concentration. The degradation term is chemical-specific. However, the degradation term is also set to zero for all contaminants except dioxin-like compounds. Note that the elimination of the loss terms may be inappropriate for certain chemicals for which the screening procedure is not intended (e.g., volatile organic compounds).

The second step is to calculate the load of contaminant to the waterbody (Tables 4.5.2 through 4.5.8) at the location of maximum combined (wet and dry) deposition (or an alternative location, as discussed in Section 3.4, Exposure Locations). Four pathways cause contaminant loading of the waterbody: 1) direct deposition; 2) runoff from impervious surfaces within the watershed; 3) runoff from pervious surfaces within the watershed; and 4) soil erosion from the watershed. Other pathways have been omitted. Direct diffusion of vapor phase pollutants into the waterbody is not a significant pathway for the chemicals included in the screening analysis. Internal transformation may be considered as a waterbody loading pathway but this pathway has also been omitted from the screening analysis. Instead, the effects of transformation processes for constituents which are transformed (e.g., inorganic mercury to methyl mercury) are implicit in the waterbody to fish tissue partitioning factor (e.g., the bioaccumulation factor for mercury). For each chemical, only the most important pathways are used.

The third step is to calculate the total waterbody concentration (in the water column and sediments) from the waterbody load (Table 4.5.9) and to partition the total concentration into a dissolved water concentration, a total water column concentration, and a bed sediment concentration (Tables 4.5.10 through 4.5.13). Only one of these three concentrations is calculated for each chemical. Chemical dissipation from within the waterbody, which may occur by degradation, volatilization, or benthic burial, has been omitted from the screening analysis. This will result in a conservative estimate of the waterbody concentration. Note that the elimination of the dissipation terms may be inappropriate for certain chemicals for which the screening procedure is not intended (e.g., volatile organic compounds).

The final step is to calculate the concentration in fish from the total water column concentration, the dissolved water concentration, or the bed sediment concentration using a

bioconcentration factor, a bioaccumulation factor, or a sediment bioaccumulation factor, as appropriate (Tables 4.5.14 through 4.5.16).

The fish ingestion pathway is used only for the subsistence fisher exposure scenario.

The two high end parameters for the fish consumption pathway are the soil mixing depth (Z) and the waterbody total suspended solids concentration (TSS). The soil mixing depth should be set to a 10th percentile (or low) value. The waterbody total suspended solids concentration should be set to a 90th percentile (or high) value.

There are a number of site-specific parameters in the fish consumption pathway, including total time of deposition (Tc), and the various parameters characterizing the waterbody. The total time of deposition should be set to the expected lifetime of the combustion source (e.g., 30 years). The following guidance is provided on the waterbody parameters:

- Waterbody surface area (WA_w): this should be estimated from local maps.
- Average volumetric flow (Vfx): average flows can be obtained from river and stream gauging stations. If data from gauging stations are not available, the average flow can be estimated based on the total upstream watershed area and the average runoff. The total upstream watershed area (in length squared units) is multiplied by a unit area surface water runoff (in length per time). The *Water Atlas of the United States* (Geraghty, et al., 1973) provides maps with isolines of annual average surface water runoff, which is defined as all flow contributions to surface water bodies, including direct runoff, shallow interflow, and groundwater recharge. Flows may vary from 10^5 m^3/yr in small streams or ponds draining less than a square kilometer to 10^9 m^3/yr or more in large rivers.
- Depth of the water column (d_w): depths can be obtained from gauging stations or be estimated based on other local data. Depths should represent the average depth of the water column, so far as is possible.
- Total watershed area (WA_L): see Section 3.7 for guidance on estimating the watershed area. This area should be the same as the effective drainage area.
- Impervious watershed area (WA_I): this is the portion of the total effective watershed area that is impervious to rainfall (e.g., roofs, driveways, streets, parking lots, etc.) and drains to the waterbody through a conveyance such as a gutter, storm sewer, ditch, or canal. It can be estimated based on land use and other local information.
- Annual average surface runoff (R): Surface runoff, R, can be estimated using the *Water Atlas of the United States* (Geraghty et al., 1973). This reference provides maps with isolines of annual average surface water runoff, which are defined as all flow contributions to surface water bodies, including direct runoff, shallow interflow, and ground water recharge. The range of values shown include 5 to 15 in/yr throughout the Midwest corn belt, 15 to 30 in/yr in the South and Northeast, 1 to 5 in/yr in the desert Southwest, and a wide range of 10 to 40 in/yr in the far West. Since these values are

total contributions and not just surface runoff, they need to be reduced to estimate surface runoff. A reduction of 50 percent, or one-half, should suffice if using the Water Atlas for the R term. More detailed, site specific procedures for estimating the amount of surface runoff, such as those based on the U.S. Soil Conservation Service curve number equation (CNE), may also be used (see, for example, U.S. EPA, 1985). (Note that all values must be converted to cm/yr.)

- USLE rainfall factor (RF): The RF term represents the influence of precipitation on erosion, and is derived from data on the frequency and intensity of storms. This value is typically derived on a storm-by-storm basis, but average annual values have been compiled (U.S. Department of Agriculture, 1982). Annual values range from < 50 for the arid western United States to > 300 for the Southeast.

Table 4.5.1. Watershed Soil Concentration Due to Deposition

Exposure Scenarios

Subsistence Fisher

Chemicals

Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis (2-ethylhexyl) phthalate 2,4-Dinitro toluene	2,6-Dinitro toluene Di(n)octyl phthalate Nitrobenzene total PCBs 2,3,7,8-TCDDioxin toxicity equivalents

Equation

2,3,7,8-TCDDioxin only:

$$Sc = \frac{Dydw + Dyww}{Z \cdot BD \cdot ks} \cdot [1 - exp(-ks \cdot Tc)] \cdot 100$$

All other chemicals:

$$Sc = \frac{Dydw + Dyww}{Z \cdot BD} \cdot Tc \cdot 100$$

Parameter	Definition	Default Value
Sc	Average watershed soil concentration after time period of deposition (mg/kg)	
Dydw	Yearly average dry depositional flux of pollutant onto the watershed ($g/m^2/yr$)	modeled (see Section 3)
Dyww	Yearly average wet depositional flux of pollutant onto the watershed ($g/m^2/yr$)	modeled (see Section 3)
ks	Total chemical loss rate constant from soil (yr^{-1})	calculated (see Table 4.1.2)
Z	Representative watershed mixing depth to which deposited pollutant is incorporated (cm)	High end: 1
BD	Representative watershed soil bulk density (g/cm^3)	1.5
Tc	Total time period over which deposition has occurred (yr)	site-specific
100	Units conversion factor ($mg\text{-}m^2/kg\text{-}cm^2$)	

Description

These equations calculate watershed soil concentration as a result of wet and dry deposition. Contaminants are assumed to be incorporated only to a finite depth (the mixing depth, Z). The first equation should be used when the soil loss term, ks, is not zero; this equation is used only for 2,3,7,8-TCDDioxin toxicity equivalents. The second equation should be used when ks is zero (for all other chemicals).

Table 4.5.2. Total Waterbody Load

Exposure Scenarios	
Subsistence Fisher	
Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis (2-ethylhexyl) phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene	Di(n)octyl phthalate Hexachlorobenzene Mercury Nitrobenzene total PCBs Pentachloronitrobenzene 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$L_T = L_{Dep} + L_{RI} + L_R + L_E$$

Parameter	Definition	Default Value
L_T	Total contaminant load to the water body (g/yr)	
L_{Dep}	Deposition of particle bound contaminant to the water body (g/yr)	calculated (see Table 4.5.3)
L_{RI}	Runoff load from impervious surfaces (g/yr)	calculated (see Table 4.5.4)
L_R	Runoff load from pervious surfaces (g/yr)	calculated (see Table 4.5.5)
L_E	Soil erosion load (g/yr)	calculated (see Table 4.5.6)

Description

This equation calculates the total average waterbody load from the deposition, runoff, and erosion loads. Not all types of loads (deposition, runoff, or erosion) are used for each chemical.

Table 4.5.3. Deposition to Waterbody

Exposure Scenarios		
Subsistence Fisher		
Chemicals		
1,3-Dinitro benzene Hexachlorobenzene	Mercury Pentachloronitrobenzene	
Equation		
$L_{Dep} = (Dyds + Dyws) \cdot WA_w$		

Parameter	Definition	Default Value
L_{Dep}	Direct deposition load (g/yr)	
Dyds	Representative yearly dry deposition rate of pollutant onto surface water body (g pollutant/m^2/yr)	modeled (see Section 3)
Dyws	Representative yearly wet deposition rate of pollutant onto surface water body (g pollutant/m^2/yr)	modeled (see Section 3)
WA_w	Water body area (m^2)	site-specific

Description
This equation calculates the average load to the waterbody from direct deposition onto the surface of the waterbody.

Table 4.5.4. Impervious Runoff Load to Waterbody

Exposure Scenarios	
Subsistence Fisher	
Chemicals	
Arsenic Beryllium 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene	Hexachlorobenzene Mercury Nitrobenzene Pentachloronitrobenzene

Equation

$$L_{RI} = (Dyww + Dydw) \cdot WA_I$$

Parameter	Definition	Default Value
L_{RI}	Impervious surface runoff load (g/yr)	
WA_I	Impervious watershed area receiving pollutant deposition (m^2)	site-specific
Dyww	Yearly wet deposition flux onto the watershed ($g/m^2/yr$)	modeled (see Section 3)
Dydw	Yearly dry deposition flux onto the watershed ($g/m^2/yr$)	modeled (see Section 3)

Description

This equation calculates the average runoff load to the waterbody from impervious surfaces in the watershed from which runoff is conveyed directly to the waterbody.

Table 4.5.5. Pervious Runoff Load to Waterbody

Exposure Scenarios

Subsistence Fisher

Chemicals

Arsenic Beryllium 2,4-Dinitro toluene	2,6-Dinitro toluene Nitrobenzene

Equation

$$L_R = R \cdot (WA_L - WA_I) \cdot \frac{Sc \cdot BD}{\theta_s + Kd_s \cdot BD} \cdot 0.01$$

Parameter	Definition	Default Value
L_R	Pervious surface runoff load (g/yr)	
R	Average annual surface runoff (cm/yr)	site-specific
Sc	Pollutant concentration in watershed soils (mg/kg)	calculated (see Table 4.5.1)
BD	Soil bulk density (g/cm^3)	1.5
Kd_s	Soil-water partition coefficient (L/kg)	chemical-specific (see Section 5)
WA_L	Total watershed area receiving pollutant deposition (m^2)	site-specific
WA_I	Impervious watershed area receiving pollutant deposition (m^2)	site-specific
0.01	Units conversion factor (kg-cm^2/mg-m^2)	
θ_s	Volumetric soil water content (cm^3/cm^3)	0.2

Description

This equation calculates the average runoff load to the waterbody from pervious soil surfaces in the watershed.

Table 4.5.6. Erosion Load to Waterbody

Exposure Scenarios	
Subsistence Fisher	
Chemicals	
Benzo(a)pyrene toxicity equivalents Bis (2-ethylhexyl) phthalate Di(n)octyl phthalate	total PCBs 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$L_E = X_e \cdot (WA_L - WA_I) \cdot SD \cdot ER \cdot \frac{Sc \cdot Kd_s \cdot BD}{\theta_s + Kd_s \cdot BD} \cdot 0.001$$

Parameter	Definition	Default Value
L_E	Soil erosion load (g/yr)	
X_e	Unit soil loss (kg/m^2/yr)	calculated (see Table 4.5.7)
Sc	Pollutant concentration in watershed soils (mg/kg)	calculated (see Table 4.5.1)
BD	Soil bulk density (g/cm^3)	1.5
θ_s	Volumetric soil water content (cm^3/cm^3)	0.2
Kd_s	Soil-water partition coefficient (L/kg)	chemical-specific (see Section 5)
WA_L	Total watershed area receiving pollutant deposition (m^2)	site-specific
WA_I	Impervious watershed area receiving pollutant deposition (m^2)	site-specific
SD	Watershed sediment delivery ratio (unitless)	calculated (see Table 4.5.8)
ER	Soil enrichment ratio (unitless)	3
0.001	Units conversion factor ([g/kg]/[mg/kg])	

Description

This equation calculates the load to the waterbody from soil erosion.

Table 4.5.7. Universal Soil Loss Equation (USLE)

Exposure Scenarios

Subsistence Fisher

Chemicals

Benzo(a)pyrene toxicity equivalents Bis (2-ethylhexyl) phthalate Di(n)octyl phthalate	total PCBs 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$X_e = RF \cdot K \cdot LS \cdot C \cdot P \cdot \frac{907.18}{0.004047}$$

Parameter	Definition	Default Value
X_e	Unit soil loss (kg/m^2/yr)	
RF	USLE rainfall (or erosivity) factor (yr^{-1})	site-specific
K	USLE erodibility factor (ton/acre)	0.36
LS	USLE length-slope factor (unitless)	1.5
C	USLE cover management factor (unitless)	0.1
P	USLE supporting practice factor (unitless)	1
907.18	Conversion factor (kg/ton)	
0.004047	Conversion factor (km^2/acre)	

Description

This equation calculates the soil loss rate from the watershed, using the Universal Soil Loss Equation; the result is used in the soil erosion load equation.

Table 4.5.8. Sediment Delivery Ratio

Exposure Scenarios		
Subsistence Fisher		
Chemicals		
Benzo(a)pyrene toxicity equivalents Bis (2-ethylhexyl) phthalate Di(n)octyl phthalate	total PCBs 2,3,7,8-TCDDioxin toxicity equivalents	
Equation		
$SD = a \cdot (WA_L)^{-b}$		
Parameter	**Definition**	**Default Value**
SD	Watershed sediment delivery ratio (unitless)	
WA_L	Watershed area receiving fallout (m^2)	site-specific
b	Empirical slope coefficient	-0.125
a	Empirical intercept coefficient	depends on watershed area; see table below
Description		
This equation calculates the sediment delivery ratio for the watershed; the result is used in the soil erosion load equation.		

Values for Empirical Intercept Coefficient, a

Watershed area (sq. miles)	"a" coefficient (unitless)
≤ 0.1	2.1
1	1.9
10	1.4
100	1.2
1,000	0.6
1 sq. mile = 2.59x10^6 m^2	

Table 4.5.9. Total Waterbody Concentration

Exposure Scenarios	
Subsistence Fisher	
Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis (2-ethylhexyl) phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene	Di(n)octyl phthalate Hexachlorobenzene Mercury Nitrobenzene total PCBs Pentachloronitrobenzene 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$C_{wtot} = \frac{L_T}{Vf_x \cdot f_{water}}$$

Parameter	Definition	Default Value
C_{wtot}	Total water body concentration, including water column and bed sediment (mg/L)	
L_T	Total chemical load into water body, including deposition, runoff, and erosion (g/yr)	calculated (see Table 4.5.2)
Vf_x	Average volumetric flow rate through water body (m^3/yr)	site-specific
f_{water}	Fraction of total water body contaminant concentration that occurs in the water column (unitless)	calculated (see Table 4.5.10)

Description

This equation calculates the total waterbody concentration, including both the water column and the bed sediment.

Table 4.5.10. Fraction in Water Column and Bed Sediment

Exposure Scenarios	
Subsistence Fisher	

Chemicals

Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis (2-ethylhexyl) phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene	Di(n)octyl phthalate Hexachlorobenzene Mercury Nitrobenzene total PCBs Pentachloronitrobenzene 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$f_{water} = \frac{(1 + Kd_{sw} \cdot TSS \cdot 10^{-6}) \cdot d_w}{(1 + Kd_{sw} \cdot TSS \cdot 10^{-6}) \cdot d_w + (\theta_{bs} + Kd_{bs} \cdot BS) \cdot d_b}$$

$$f_{benth} = 1 - f_{water}$$

Parameter	Definition	Default Value
f_{water}	Fraction of total water body contaminant concentration that occurs in the water column (unitless)	
Kd_{sw}	Suspended sediment/surface water partition coefficient (L/kg)	chemical-specific (see Section 5)
TSS	Total suspended solids (mg/L)	High end: 80
10^{-6}	Conversion factor (kg/mg)	
d_w	Depth of the water column (m)	site-specific
d_b	Depth of the upper benthic layer (m)	0.03
θ_{bs}	Bed sediment porosity (L_{water}/L)	0.5
Kd_{bs}	Bed sediment/sediment pore water partition coefficient (L/kg)	chemical-specific (see Section 5)
BS	Bed sediment concentration (g/cm^3)	1.0
f_{benth}	Fraction of total water body contaminant concentration that occurs in the bed sediment (unitless)	

Description

These equations calculate the fraction of total waterbody concentration occurring in the water column and the bed sediments.

Table 4.5.11. Total Water Column Concentration

Exposure Scenarios

Subsistence Fisher

Chemicals

Benzo(a)pyrene toxicity equivalents
Bis (2-ethylhexyl) phthalate
Di(n)octyl phthalate

Hexachlorobenzene
Mercury

Equation

$$C_{wt} = f_{water} \cdot C_{wtot} \cdot \frac{d_w + d_b}{d_w}$$

Parameter	Definition	Default Value
C_{wt}	Total concentration in water column (mg/L)	
f_{water}	Fraction of total water body contaminant concentration that occurs in the water column (unitless)	calculated (see Table 4.5.10)
C_{wtot}	Total water concentration in surface water system, including water column and bed sediment (mg/L)	calculated (see Table 4.5.9)
d_b	Depth of upper benthic layer (m)	0.03
d_w	Depth of the water column (m)	site-specific

Description

This equation calculates the total water column concentration of contaminant; this includes both dissolved contaminant and contaminant sorbed to suspended solids.

Table 4.5.12. Dissolved Water Concentration

Exposure Scenarios	
Subsistence Fisher	
Chemicals	
Arsenic Beryllium 1,3-Dinitro benzene 2,4-Dinitro toluene	2,6-Dinitro toluene Nitrobenzene Pentachloronitrobenzene
Equation	

$$C_{dw} = \frac{C_{wt}}{1 + Kd_{sw} \cdot TSS \cdot 10^{-6}}$$

Parameter	Definition	Default Value
C_{dw}	Dissolved phase water concentration (mg/L)	
C_{wt}	Total concentration in water column (mg/L)	calculated (see Table 4.5.11)
Kd_{sw}	Suspended sediment/surface water partition coefficient (L/kg)	chemical-specific (see Section 5)
TSS	Total suspended solids (mg/L)	High end: 80

Description

This equation calculates the concentration of contaminant dissolved in the water column.

Table 4.5.13. Concentration Sorbed to Bed Sediment

Exposure Scenarios	
Subsistence Fisher	
Chemicals	
total PCBs	2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$C_{sb} = f_{benth} \cdot C_{wt} \cdot \frac{Kd_{bs}}{\theta_{bs} + Kd_{bs} \cdot BS} \cdot \frac{d_w + d_b}{d_b}$$

Parameter	Definition	Default Value
C_{sb}	Concentration sorbed to bed sediments (mg/kg)	
f_{benth}	Fraction of total water body contaminant concentration that occurs in the bed sediment (unitless)	calculated (see Table 4.5.10)
C_{wtot}	Total water concentration in surface water system, including water column and bed sediment (mg/L)	calculated (see Table 4.5.9)
d_w	Total depth of water column (m)	site-specific
d_b	Depth of the upper benthic layer (m)	0.03
θ_{bs}	Bed sediment porosity (unitless)	0.5
Kd_{bs}	Bed sediment/sediment pore water partition coefficient (L/kg)	chemical-specific (see Section 5)
BS	Bed sediment concentration (g/cm^3)	1.0

Description

This equation calculates the concentration of contaminant sorbed to bed sediments.

Table 4.5.14. Fish Concentration from Dissolved Water Concentration

<table>
<tr><th colspan="3">Exposure Scenarios</th></tr>
<tr><td colspan="3">Subsistence Fisher</td></tr>
<tr><th colspan="3">Chemicals</th></tr>
<tr><td colspan="2">Arsenic
Beryllium
1,3-Dinitro benzene
2,4-Dinitro toluene</td><td>2,6-Dinitro toluene
Nitrobenzene
Pentachloronitrobenzene</td></tr>
<tr><th colspan="3">Equation</th></tr>
<tr><td colspan="3">$$C_{fish} = C_{dw} \cdot BCF$$</td></tr>
<tr><th>Parameter</th><th>Definition</th><th>Default Value</th></tr>
<tr><td>C_{fish}</td><td>Fish concentration (mg/kg)</td><td></td></tr>
<tr><td>C_{dw}</td><td>Dissolved water concentration (mg/L)</td><td>calculated (see Table 4.5.12)</td></tr>
<tr><td>BCF</td><td>Bioconcentration factor (L/kg)</td><td>chemical-specific (see Section 5)</td></tr>
<tr><th colspan="3">Description</th></tr>
<tr><td colspan="3">This equation calculates fish concentration from dissolved water concentration, using a bioconcentration factor.</td></tr>
</table>

Table 4.5.15. Fish Concentration from Total Water Column Concentration

Exposure Scenarios
Subsistence Fisher

Chemicals	
Benzo(a)pyrene toxicity equivalents Bis (2-ethylhexyl) phthalate Di(n)octyl phthalate	Hexachlorobenzene Mercury

Equation

$$C_{fish} = C_{wt} \cdot BAF$$

Parameter	Definition	Default Value
C_{fish}	Fish concentration (mg/kg)	
C_{wt}	Total water column concentration (mg/L)	calculated (see Table 4.5.11)
BAF	Bioaccumulation factor (L/kg)	chemical-specific (see Section 5)

Description

This equation calculates fish concentration from total water column concentration, using a bioaccumulation factor.

Table 4.5.16. Fish Concentration from Bed Sediments

Exposure Scenarios	
Subsistence Fisher	
Chemicals	
total PCBs	2,3,7,8-TCDDioxin toxicity equivalents
Equation	

$$C_{fish} = \frac{C_{sb} \cdot f_{lipid} \cdot BSAF}{OC_{sed}}$$

Parameter	Definition	Default Value
C_{fish}	Fish concentration (mg/kg)	
C_{sb}	Concentration of contaminant sorbed to bed sediment (mg/kg)	calculated (see Table 4.5.13)
f_{lipid}	Fish lipid content (fraction)	0.07
BSAF	Biota to sediment accumulation factor (unitless)	chemical-specific (see Section 5)
OC_{sed}	Fraction organic carbon in bottom sediment (unitless)	0.04

Description

This equation calculates fish concentration from bed sediment concentration, using a biota-to-sediment accumulation factor.

5. CHEMICAL-SPECIFIC PARAMETERS

5.1 Toxicity Equivalency Factors for Dioxin-Like Compounds and Polycyclic Aromatic Hydrocarbons

For the screening analysis, the emissions of all 2,3,7,8 substituted dibenzo(p)dioxins and dibenzofurans are converted to 2,3,7,8-tetrachlorodibenzo(p)dioxin toxicity equivalents (2,3,7,8-TCDD-TEQ) following EPA's *Interim Procedures for Estimating Risks Associated with Mixtures of Chlorinated Dibenzo-p-Dioxins and Dibenzofurans (CDDs and CDFs)* (U.S. EPA, 1989). Table 5.1.1 presents the toxicity equivalency factor (TEF) for each congener and the calculations necessary for estimating the 2,3,7,8-TCDD-TEQ emissions. The 2,3,7,8-TCDD-TEQ chemical group is modeled using the fate and transport properties of the 2,3,7,8-TCDD congener.

Similarly, the emissions of seven polycyclic aromatic hydrocarbons (PAH's) are converted to benzo(a)pyrene toxicity equivalents (BaP-TEQ) following EPA's *Provisional Guidance for the Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons* (OHEA, 1993). Table 5.1.2 presents the toxicity equivalency factor (TEF) for each PAH and the calculations necessary for estimating the BaP-TEQ emissions. The BaP-TEQ chemical group is modeled using the fate and transport properties of benzo(a)pyrene.

Table 5.1.1. Toxicity Equivalence Factors (TEF's) for Dioxin and Furan Emissions

Congener	Emission Rate (g/s)	x	TEF [1]	=	2,3,7,8-TCDD TEQ Emission Rate (g/s)
2,3,7,8-Tetrachlorodibenzo(p)dioxin	facility-specific	x	1	=	
1,2,3,7,8-Pentachlorodibenzo(p)dioxin	facility-specific	x	0.5	=	
1,2,3,4,7,8-Hexachlorodibenzo(p)dioxin	facility-specific	x	0.1	=	
1,2,3,6,7,8-Hexachlorodibenzo(p)dioxin	facility-specific	x	0.1	=	
1,2,3,7,8,9-Hexachlorodibenzo(p)dioxin	facility-specific	x	0.1	=	
1,2,3,6,7,8,9-Heptachlorodibenzo(p)dioxin	facility-specific	x	0.01	=	
Octachlorodibenzo(p)dioxin	facility-specific	x	0.001	=	
2,3,7,8-Tetrachlorodibenzofuran	facility-specific	x	0.1	=	
1,2,3,7,8-Pentachlorodibenzofuran	facility-specific	x	0.05	=	
2,3,4,7,8-Pentachlorodibenzofuran	facility-specific	x	0.5	=	
1,2,3,4,7,8-Hexachlorodibenzofuran	facility-specific	x	0.1	=	
1,2,3,6,7,8-Hexachlorodibenzofuran	facility-specific	x	0.1	=	
1,2,3,7,8,9-Hexachlorodibenzofuran	facility-specific	x	0.1	=	
2,3,4,6,7,8-Hexachlorodibenzofuran	facility-specific	x	0.1	=	
1,2,3,4,6,7,8-Heptachlorodibenzofuran	facility-specific	x	0.01	=	
1,2,3,4,7,8,9-Heptachlorodibenzofuran	facility-specific	x	0.01	=	
Octachlorodibenzofuran	facility-specific	x	0.001	=	
	Total 2,3,7,8-TCDD-TEQ Emission Rate	=	Σ	=	

[1] (EPA, 1989)

Table 5.1.2. Toxicity Equivalence Factors (TEF's) for PAH Emissions

PAH	Emission Rate (g/s)	x	TEF[1]	=	BaP TEQ Emission Rate (g/s)
Benzo(a)pyrene (BaP)	facility-specific	x	1.0	=	
Benz(a)anthracene	facility-specific	x	0.1	=	
Benzo(b)fluoranthene	facility-specific	x	0.1	=	
Benzo(k)fluoranthene	facility-specific	x	0.01	=	
Chrysene	facility-specific	x	0.001	=	
Dibenz(a,h)anthracene	facility-specific	x	1.0	=	
Indeno(1,2,3-cd)pyrene	facility-specific	x	0.1	=	
	Total BaP-TEQ Emission Rate	=	Σ	=	

[1] (OHEA, 1993)

5.2 Other Chemical Parameters

This section gives the values for the chemical-specific parameters for the pathway equations in Section 4, along with the health related criteria or benchmarks for characterizing risk that are used in Section 6. The data are organized by chemical in alphabetical order. There are 15 tables, one for each chemical or group of chemicals, as indicated in the text box. The data in the tables include physical/chemical properties data, biological transfer factors, and health criteria or benchmarks. For each parameter, the tables indicate the equations in Section 4 or Section 6 for which the parameter is used. A value of NA indicates that the value is not applicable for that chemical. Although a value for the parameter may exist for the chemical, it is not included here because it is not needed for the screening analysis. (No table is provided for lead; only a soil concentration is calculated for lead, a calculation which requires no chemical-specific inputs.)

Chemical	Table
Arsenic	5.2.1.
Beryllium	5.2.2.
Benzo(a)pyrene Toxicity Equivalents	5.2.3.
Bis(2-ethylhexyl) phthalate	5.2.4.
1,3-Dinitro benzene	5.2.5.
2,4-Dinitro toluene	5.2.6.
2,6-Dinitro toluene	5.2.7.
Di(n)octyl phthalate	5.2.8.
Hexachlorobenzene	5.2.9.
Mercury	5.2.10.
Nitrobenzene	5.2.11
total PCBs	5.2.12.
Pentachloronitrobenzene	5.2.13.
Pentachlorophenol	5.2.14.
2,3,7,8-TCDDioxin Toxicity Equivalents	5.2.15.

Table 5.2.1. Chemical-Specific Inputs for Arsenic

Parameter	Definition	Equation	Value
Chemical/Physical Properties			
ksg	Soil loss constant due to degradation (yr^{-1})	4.1.2	NA
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	4.2.2, 4.4.3	0
Kd_s	Soil-water partition coefficient (mL/g or L/kg)	4.3.2, 4.5.5, 4.5.6	29
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)	4.5.10, 4.5.12	220
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)	4.5.10, 4.5.13	120
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([μg pollutant/g plant tissue DW]/[μg pollutant/g air])	4.2.2, 4.4.3	NA
RCF	Ratio of concentration in the roots to concentration in soil pore water ([μg pollutant/g plant tissue FW]/[μg pollutant/mL pore water])	4.3.2	0.008
Ba_{beef}	Biotransfer factor for beef (day/kg)	4.4.4	0.002
Ba_{milk}	Biotransfer factor for milk (day/kg)	4.5.5	0.006
BCF	Fish bioconcentration factor (L/kg)	4.5.14	44
BAF	Fish bioaccumulation factor (L/kg)	4.5.15	NA
BSAF	Fish biota to sediment accumulation factor (unitless)	4.5.16	NA
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	4.2.1, 4.4.2	0.1
Health Benchmarks			
CSF	Cancer Slope Factor (per mg/kg/day)	6.1.5, 6.2.5, 6.3.4, 6.4.4	1.75
RfD	Reference Dose (mg/kg/day)	6.1.6, 6.2.6, 6.3.5, 6.4.5	3E-4

Table 5.2.2. Chemical-Specific Inputs for Beryllium

Parameter	Definition	Equation	Value
Chemical/Physical Properties			
ksg	Soil loss constant due to degradation (yr^{-1})	4.1.2	NA
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	4.2.2, 4.4.3	0
Kd_s	Soil-water partition coefficient (mL/g or L/kg)	4.3.2, 4.5.5, 4.5.6	70
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)	4.5.10, 4.5.12	525
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)	4.5.10, 4.5.13	280
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([μg pollutant/g plant tissue DW]/[μg pollutant/g air])	4.2.2, 4.4.3	NA
RCF	Ratio of concentration in the roots to concentration in soil pore water ([μg pollutant/g plant tissue FW]/[μg pollutant/mL pore water])	4.3.2	0.0015
Ba_{beef}	Biotransfer factor for beef (day/kg)	4.4.4	0.001
Ba_{milk}	Biotransfer factor for milk (day/kg)	4.5.5	9E-7
BCF	Fish bioconcentration factor (L/kg)	4.5.14	20
BAF	Fish bioaccumulation factor (L/kg)	4.5.15	NA
BSAF	Fish biota to sediment accumulation factor (unitless)	4.5.16	NA
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	4.2.1, 4.4.2	0.1
Health Benchmarks			
CSF	Cancer Slope Factor (per mg/kg/day)	6.1.5, 6.2.5, 6.3.4, 6.4.4	4.3E+0
RfD	Reference Dose (mg/kg/day)	6.1.6, 6.2.6, 6.3.5, 6.4.5	5E-3

Table 5.2.3. Chemical-Specific Inputs for Benzo(a)pyrene Toxicity Equivalents

Parameter	Definition	Equation	Value
Chemical/Physical Properties			
ksg	Soil loss constant due to degradation (yr^{-1})	4.1.2	NA
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	4.2.2, 4.4.3	0.4
Kd_s	Soil-water partition coefficient (mL/g or L/kg)	4.3.2, 4.5.5, 4.5.6	12,000
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)	4.5.10, 4.5.12	90,000
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)	4.5.10, 4.5.13	48,000
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([μg pollutant/g plant tissue DW]/[μg pollutant/g air])	4.2.2, 4.4.3	1,300,000
RCF	Ratio of concentration in the roots to concentration in soil pore water ([μg pollutant/g plant tissue FW]/[μg pollutant/mL pore water])	4.3.2	1,600
Ba_{beef}	Biotransfer factor for beef (day/kg)	4.4.4	0.034
Ba_{milk}	Biotransfer factor for milk (day/kg)	4.5.5	0.011
BCF	Fish bioconcentration factor (L/kg)	4.5.14	NA
BAF	Fish bioaccumulation factor (L/kg)	4.5.15	1,000,000
BSAF	Fish biota to sediment accumulation factor (unitless)	4.5.16	NA
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	4.2.1, 4.4.2	1
Health Benchmarks			
CSF	Cancer Slope Factor (per mg/kg/day)	6.1.5, 6.2.5, 6.3.4, 6.4.4	7.3
RfD	Reference Dose (mg/kg/day)	6.1.6, 6.2.6, 6.3.5, 6.4.5	NA

Table 5.2.4. Chemical-Specific Inputs for Bis (2-ethylhexyl) phthalate

Parameter	Definition	Equation	Value
Chemical/Physical Properties			
ksg	Soil loss constant due to degradation (yr^{-1})	4.1.2	NA
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	4.2.2, 4.4.3	0.8
Kd_s	Soil-water partition coefficient (mL/g or L/kg)	4.3.2, 4.5.5, 4.5.6	46,000
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)	4.5.10, 4.5.12	350,000
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)	4.5.10, 4.5.13	180,000
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([μg pollutant/g plant tissue DW]/[μg pollutant/g air])	4.2.2, 4.4.3	640,000
RCF	Ratio of concentration in the roots to concentration in soil pore water ([μg pollutant/g plant tissue FW]/[μg pollutant/mL pore water])	4.3.2	4,500
Ba_{beef}	Biotransfer factor for beef (day/kg)	4.4.4	NA
Ba_{milk}	Biotransfer factor for milk (day/kg)	4.5.5	NA
BCF	Fish bioconcentration factor (L/kg)	4.5.14	NA
BAF	Fish bioaccumulation factor (L/kg)	4.5.15	66,000
BSAF	Fish biota to sediment accumulation factor (unitless)	4.5.16	NA
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	4.2.1, 4.4.2	1
Health Benchmarks			
CSF	Cancer Slope Factor (per mg/kg/day)	6.1.5, 6.2.5, 6.3.4, 6.4.4	1.4E-2
RfD	Reference Dose (mg/kg/day)	6.1.6, 6.2.6, 6.3.5, 6.4.5	2E-2

Table 5.2.5. Chemical-Specific Inputs for 1,3-Dinitro benzene

Parameter	Definition	Equation	Value
Chemical/Physical Properties			
ksg	Soil loss constant due to degradation (yr^{-1})	4.1.2	NA
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	4.2.2, 4.4.3	1
Kd_s	Soil-water partition coefficient (mL/g or L/kg)	4.3.2, 4.5.5, 4.5.6	0.28
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)	4.5.10, 4.5.12	2
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)	4.5.10, 4.5.13	1.1
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([μg pollutant/g plant tissue DW]/[μg pollutant/g air])	4.2.2, 4.4.3	0.0068
RCF	Ratio of concentration in the roots to concentration in soil pore water ([μg pollutant/g plant tissue FW]/[μg pollutant/mL pore water])	4.3.2	1.25
Ba_{beef}	Biotransfer factor for beef (day/kg)	4.4.4	7.9E-7
Ba_{milk}	Biotransfer factor for milk (day/kg)	4.5.5	2.5E-7
BCF	Fish bioconcentration factor (L/kg)	4.5.14	1.4
BAF	Fish bioaccumulation factor (L/kg)	4.5.15	NA
BSAF	Fish biota to sediment accumulation factor (unitless)	4.5.16	NA
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	4.2.1, 4.4.2	0.1
Health Benchmarks			
CSF	Cancer Slope Factor (per mg/kg/day)	6.1.5, 6.2.5, 6.3.4, 6.4.4	NA
RfD	Reference Dose (mg/kg/day)	6.1.6, 6.2.6, 6.3.5, 6.4.5	1E-4

Table 5.2.6. Chemical-Specific Inputs for 2,4-Dinitro toluene

Parameter	Definition	Equation	Value
Chemical/Physical Properties			
ksg	Soil loss constant due to degradation (yr^{-1})	4.1.2	NA
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	4.2.2, 4.4.3	1
Kd_s	Soil-water partition coefficient (mL/g or L/kg)	4.3.2, 4.5.5, 4.5.6	0.87
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)	4.5.10, 4.5.12	6.5
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)	4.5.10, 4.5.13	3.5
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([μg pollutant/g plant tissue DW]/[μg pollutant/g air])	4.2.2, 4.4.3	150
RCF	Ratio of concentration in the roots to concentration in soil pore water ([μg pollutant/g plant tissue FW]/[μg pollutant/mL pore water])	4.3.2	1.9
Ba_{beef}	Biotransfer factor for beef (day/kg)	4.4.4	2.5E-6
Ba_{milk}	Biotransfer factor for milk (day/kg)	4.5.5	7.9E-7
BCF	Fish bioconcentration factor (L/kg)	4.5.14	3.2
BAF	Fish bioaccumulation factor (L/kg)	4.5.15	NA
BSAF	Fish biota to sediment accumulation factor (unitless)	4.5.16	NA
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	4.2.1, 4.4.2	0.1
Health Benchmarks			
CSF	Cancer Slope Factor (per mg/kg/day)	6.1.5, 6.2.5, 6.3.4, 6.4.4	6.8E-1
RfD	Reference Dose (mg/kg/day)	6.1.6, 6.2.6, 6.3.5, 6.4.5	2E-3

Table 5.2.7. Chemical-Specific Inputs for 2,6-Dinitro toluene

Parameter	Definition	Equation	Value
Chemical/Physical Properties			
ksg	Soil loss constant due to degradation (yr^{-1})	4.1.2	NA
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	4.2.2, 4.4.3	1
Kd_s	Soil-water partition coefficient (mL/g or L/kg)	4.3.2, 4.5.5, 4.5.6	0.67
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)	4.5.10, 4.5.12	5
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)	4.5.10, 4.5.13	2.7
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([μg pollutant/g plant tissue DW]/[μg pollutant/g air])	4.2.2, 4.4.3	130
RCF	Ratio of concentration in the roots to concentration in soil pore water ([μg pollutant/g plant tissue FW]/[μg pollutant/mL pore water])	4.3.2	1.7
Ba_{beef}	Biotransfer factor for beef (day/kg)	4.4.4	1.9E-6
Ba_{milk}	Biotransfer factor for milk (day/kg)	4.5.5	6.1E-7
BCF	Fish bioconcentration factor (L/kg)	4.5.14	2.6
BAF	Fish bioaccumulation factor (L/kg)	4.5.15	NA
BSAF	Fish biota to sediment accumulation factor (unitless)	4.5.16	NA
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	4.2.1, 4.4.2	0.1
Health Benchmarks			
CSF	Cancer Slope Factor (per mg/kg/day)	6.1.5, 6.2.5, 6.3.4, 6.4.4	6.8E-1
RfD	Reference Dose (mg/kg/day)	6.1.6, 6.2.6, 6.3.5, 6.4.5	1E-3

Table 5.2.8. Chemical-Specific Inputs for Di(n)octyl phthalate

Parameter	Definition	Equation	Value
Chemical/Physical Properties			
ksg	Soil loss constant due to degradation (yr^{-1})	4.1.2	NA
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	4.2.2, 4.4.3	0.8
Kd_s	Soil-water partition coefficient (mL/g or L/kg)	4.3.2, 4.5.5, 4.5.6	19,000,000
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)	4.5.10, 4.5.12	140,000,000
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)	4.5.10, 4.5.13	76,000,000
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([μg pollutant/g plant tissue DW]/[μg pollutant/g air])	4.2.2, 4.4.3	6.6E+9
RCF	Ratio of concentration in the roots to concentration in soil pore water ([μg pollutant/g plant tissue FW]/[μg pollutant/mL pore water])	4.3.2	460,000
Ba_{beef}	Biotransfer factor for beef (day/kg)	4.4.4	NA
Ba_{milk}	Biotransfer factor for milk (day/kg)	4.5.5	NA
BCF	Fish bioconcentration factor (L/kg)	4.5.14	NA
BAF	Fish bioaccumulation factor (L/kg)	4.5.15	66,000
BSAF	Fish biota to sediment accumulation factor (unitless)	4.5.16	NA
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	4.2.1, 4.4.2	1
Health Benchmarks			
CSF	Cancer Slope Factor (per mg/kg/day)	6.1.5, 6.2.5, 6.3.4, 6.4.4	NA
RfD	Reference Dose (mg/kg/day)	6.1.6, 6.2.6, 6.3.5, 6.4.5	2E-2

Table 5.2.11. Chemical-Specific Inputs for Nitrobenzene

Parameter	Definition	Equation	Value
Chemical/Physical Properties			
ksg	Soil loss constant due to degradation (yr^{-1})	4.1.2	NA
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	4.2.2, 4.4.3	1
Kd_s	Soil-water partition coefficient (mL/g or L/kg)	4.3.2, 4.5.5, 4.5.6	0.6
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)	4.5.10, 4.5.12	4.5
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)	4.5.10, 4.5.13	2.4
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([µg pollutant/g plant tissue DW]/[µg pollutant/g air])	4.2.2, 4.4.3	0.7
RCF	Ratio of concentration in the roots to concentration in soil pore water ([µg pollutant/g plant tissue FW]/[µg pollutant/mL pore water])	4.3.2	1.6
Ba_{beef}	Biotransfer factor for beef (day/kg)	4.4.4	1.7E-6
Ba_{milk}	Biotransfer factor for milk (day/kg)	4.5.5	5.4E-7
BCF	Fish bioconcentration factor (L/kg)	4.5.14	2.4
BAF	Fish bioaccumulation factor (L/kg)	4.5.15	NA
BSAF	Fish biota to sediment accumulation factor (unitless)	4.5.16	NA
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	4.2.1, 4.4.2	0.1
Health Benchmarks			
CSF	Cancer Slope Factor (per mg/kg/day)	6.1.5, 6.2.5, 6.3.4, 6.4.4	NA
RfD	Reference Dose (mg/kg/day)	6.1.6, 6.2.6, 6.3.5, 6.4.5	5E-4

Table 5.2.12. Chemical-Specific Inputs for total PCBs

Parameter	Definition	Equation	Value
Chemical/Physical Properties			
ksg	Soil loss constant due to degradation (yr^{-1})	4.1.2	NA
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	4.2.2, 4.4.3	1
Kd_s	Soil-water partition coefficient (mL/g or L/kg)	4.3.2, 4.5.5, 4.5.6	4,300
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)	4.5.10, 4.5.12	32,000
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)	4.5.10, 4.5.13	17,000
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([μg pollutant/g plant tissue DW]/[μg pollutant/g air])	4.2.2, 4.4.3	4,200
RCF	Ratio of concentration in the roots to concentration in soil pore water ([μg pollutant/g plant tissue FW]/[μg pollutant/mL pore water])	4.3.2	2,100
Ba_{beef}	Biotransfer factor for beef (day/kg)	4.4.4	0.05
Ba_{milk}	Biotransfer factor for milk (day/kg)	4.5.5	0.016
BCF	Fish bioconcentration factor (L/kg)	4.5.14	NA
BAF	Fish bioaccumulation factor (L/kg)	4.5.15	NA
BSAF	Fish biota to sediment accumulation factor (unitless)	4.5.16	1.6
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	4.2.1, 4.4.2	1
Health Benchmarks			
CSF	Cancer Slope Factor (per mg/kg/day)	6.1.5, 6.2.5, 6.3.4, 6.4.4	7.7
RfD	Reference Dose (mg/kg/day)	6.1.6, 6.2.6, 6.3.5, 6.4.5	NA

Table 5.2.13. Chemical-Specific Inputs for Pentachloronitrobenzene

Parameter	Definition	Equation	Value
Chemical/Physical Properties			
ksg	Soil loss constant due to degradation (yr^{-1})	4.1.2	NA
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	4.2.2, 4.4.3	1
Kd_s	Soil-water partition coefficient (mL/g or L/kg)	4.3.2, 4.5.5, 4.5.6	380
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)	4.5.10, 4.5.12	2,900
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)	4.5.10, 4.5.13	1,500
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([μg pollutant/g plant tissue DW]/[μg pollutant/g air])	4.2.2, 4.4.3	0.79
RCF	Ratio of concentration in the roots to concentration in soil pore water ([μg pollutant/g plant tissue FW]/[μg pollutant/mL pore water])	4.3.2	110
Ba_{beef}	Biotransfer factor for beef (day/kg)	4.4.4	0.0011
Ba_{milk}	Biotransfer factor for milk (day/kg)	4.5.5	0.00035
BCF	Fish bioconcentration factor (L/kg)	4.5.14	140
BAF	Fish bioaccumulation factor (L/kg)	4.5.15	NA
BSAF	Fish biota to sediment accumulation factor (unitless)	4.5.16	NA
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	4.2.1, 4.4.2	1
Health Benchmarks			
CSF	Cancer Slope Factor (per mg/kg/day)	6.1.5, 6.2.5, 6.3.4, 6.4.4	2.6E-1
RfD	Reference Dose (mg/kg/day)	6.1.6, 6.2.6, 6.3.5, 6.4.5	3E-3

Table 5.2.14. Chemical-Specific Inputs for Pentachlorophenol

Parameter	Definition	Equation	Value
Chemical/Physical Properties			
ksg	Soil loss constant due to degradation (yr^{-1})	4.1.2	NA
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	4.2.2, 4.4.3	1
Kd_s	Soil-water partition coefficient (mL/g or L/kg)	4.3.2, 4.5.5, 4.5.6	1,100
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)	4.5.10, 4.5.12	8,300
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)	4.5.10, 4.5.13	4,400
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([μg pollutant/g plant tissue DW]/[μg pollutant/g air])	4.2.2, 4.4.3	5,100
RCF	Ratio of concentration in the roots to concentration in soil pore water ([μg pollutant/g plant tissue FW]/[μg pollutant/mL pore water])	4.3.2	250
Ba_{beef}	Biotransfer factor for beef (day/kg)	4.4.4	0.003
Ba_{milk}	Biotransfer factor for milk (day/kg)	4.5.5	0.00096
BCF	Fish bioconcentration factor (L/kg)	4.5.14	NA
BAF	Fish bioaccumulation factor (L/kg)	4.5.15	NA
BSAF	Fish biota to sediment accumulation factor (unitless)	4.5.16	NA
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	4.2.1, 4.4.2	1
Health Benchmarks			
CSF	Cancer Slope Factor (per mg/kg/day)	6.1.5, 6.2.5, 6.3.4, 6.4.4	1.2E-1
RfD	Reference Dose (mg/kg/day)	6.1.6, 6.2.6, 6.3.5, 6.4.5	3E-2

Table 5.2.15. Chemical-Specific Inputs for 2,3,7,8-TCDDioxin Toxicity Equivalents

Parameter	Definition	Equation	Value
Chemical/Physical Properties			
ksg	Soil loss constant due to degradation (yr^{-1})	4.1.2	0.07
Fv	Fraction of pollutant air concentration present in the vapor phase (dimensionless)	4.2.2, 4.4.3	0.6
Kd_s	Soil-water partition coefficient (mL/g or L/kg)	4.3.2, 4.5.5, 4.5.6	25,000
Kd_{sw}	Suspended sediment-surface water partition coefficient (L/kg)	4.5.10, 4.5.12	190,000
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient (L/kg)	4.5.10, 4.5.13	100,000
Transfer Factors			
Bv	Air-to-plant biotransfer factor ([μg pollutant/g plant tissue DW]/[μg pollutant/g air])	4.2.2, 4.4.3	270,000
RCF	Ratio of concentration in the roots to concentration in soil pore water ([μg pollutant/g plant tissue FW]/[μg pollutant/mL pore water])	4.3.2	3,900
Ba_{beef}	Biotransfer factor for beef (day/kg)	4.4.4	0.11
Ba_{milk}	Biotransfer factor for milk (day/kg)	4.5.5	0.035
BCF	Fish bioconcentration factor (L/kg)	4.5.14	NA
BAF	Fish bioaccumulation factor (L/kg)	4.5.15	NA
BSAF	Fish biota to sediment accumulation factor (unitless)	4.5.16	0.09
Other Parameters			
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	4.2.1, 4.4.2	1
Health Benchmarks			
CSF	Cancer Slope Factor (per mg/kg/day)	6.1.5, 6.2.5, 6.3.4, 6.4.4	1.56E+5
RfD	Reference Dose (mg/kg/day)	6.1.6, 6.2.6, 6.3.5, 6.4.5	NA

6. RISK CHARACTERIZATION

Characterization of risk is the final step of the screening analysis. In this step, for each exposure scenario the health effects criteria or benchmarks are used in conjunction with dose estimates which are calculated for each exposure pathway to arrive at the risk assessment endpoints. The assessment endpoints of the screening analysis are as follows: a) the increased probability of cancer in an individual over a lifetime, referred to as the excess lifetime individual cancer risk (or simply, individual cancer risk) arising from both oral and inhalation routes of exposure; b) for oral exposures, a measure of an individual's exposure to chemicals with noncancer health effects relative to the reference dose (RfD), referred to as the hazard quotient; c) for inhalation exposures, a hazard quotient relative to the reference concentration (RfC) in air; and d) where appropriate, a hazard index which represents the combined hazard quotients for those chemicals with the same noncancer health effects. Population risk is not an assessment endpoint for the screening analysis. Although oral and inhalation routes of exposure are handled separately in the screening analysis, the individual risks associated with exposures to carcinogenic chemicals are combined for the oral and inhalation routes of exposure.

Indirect Exposures

For indirect exposures, a series of tables is provided for each exposure scenario. The tables are used for estimating individual cancer risk and hazard quotients for the various chemicals and for combining the cancer risks and hazard quotients across pathways and chemicals as appropriate. Each equation is presented on a separate table. The table provides the mathematical form of the equation, lists the chemicals for which the equation is to be used, identifies the parameters in the equation, and provides the parameter values (or, if calculated, the tables from which the values are obtained). It should be noted that not all equations are used for all chemicals. Specifically, calculations of individual cancer risks, hazard quotients, and hazard indices address different (albeit overlapping) lists of chemicals. There are four sets of tables presented in four sections as indicated in the text box.

Section 6.1	**Subsistence Farmer** **Tables 6.1.1. - 6.1.9.**
Section 6.2	**Subsistence Fisher** **Tables 6.2.1. - 6.2.9.**
Section 6.3	**Adult Resident** **Tables 6.3.1. - 6.3.8.**
Section 6.4	**Child Resident** **Tables 6.4.1. - 6.4.8.**

For each of the four exposure scenarios, an estimate is made of the dose (or intake) of each contaminant from all oral routes of exposure. Thus, for the subsistence farmer, the daily intake of each contaminant is calculated for soil ingestion (Table 6.1.1), above-ground and below-ground (i.e., root) vegetable ingestion (Table 6.1.2), and beef and milk ingestion (Table 6.1.3). The total daily oral intake of a contaminant is calculated by adding together the intake from each pathway (Table 6.1.4). For each carcinogen, the excess lifetime individual cancer risk is calculated using the cancer slope factor and total daily intake (Table 6.1.5). For each chemical with noncancer health effects, a hazard quotient (HQ) is calculated using the RfD and the total daily intake (Table 6.1.6). For the carcinogens, cancer risks are added across chemicals (Table 6.1.7). For the subsistence farmer this involves adding the cancer risk from all indirect exposures to eleven carcinogenic chemicals, namely arsenic, beryllium, benzo(a)pyrene toxicity equivalents, bis(2-ethylhexyl) phthalate, 2,4-dinitro toluene, 2,6-dinitro toluene, hexachlorobenzene, total PCBs, pentachloronitrobenzene, pentachlorophenol, and 2,3,7,8-TCDDioxin toxicity equivalents. For noncancer health effects, hazard quotients are added across chemicals only when they target the same organ. Five chemicals, bis(2-ethylhexyl) phthalate, hexachlorobenzene, pentachloronitrobenzene, pentachlorophenol, and di(n)octyl phthalate, have systemic effects on the liver. Therefore, the hazard quotients from these five chemicals are added together to calculate an overall hazard index for liver effects (Table. 6.1.8). Three chemicals, 2,4-dinitro toluene, 2,6-dinitro toluene, and mercury, have systemic effects on the central nervous system. Therefore, the hazard quotients from these three chemicals are added together to calculate an overall hazard index for neurotoxic effects (Table 6.1.9).

Lead

Childhood exposures to lead in soil are assessed by comparing the estimated soil lead level at the location of maximum combined (wet and dry) deposition (or an alternative location, as discussed in Section 3.4, Exposure Locations) to the soil health-based level given in the Implementation Guidance. Childhood and adult exposures to airborne lead are assessed by comparing the maximum estimated air concentration (or the highest air concentration from an alternative location, as discussed in Section 3.4, Exposure Locations) to the air health-based level given in the Implementation Guidance. No hazard quotient is calculated and no other exposure pathways are considered for lead.

Infant Exposure Through Breast Milk

The draft Addendum to the *Indirect Exposure Document* presents procedures for calculating infant exposures to dioxins and other lipophilic compounds through ingestion of human breast milk. The procedures are based on the intake of the contaminant by the mother. The exposure to an infant from breast feeding can be presented as an average daily dose (ADD) or a lifetime average daily dose (LADD). The ADD to the infant over a one year averaging time is predicted to be much higher (e.g. 30 to 60 times higher) than the ADD for the mother. However, if a 70 year averaging time is used, then the LADD to the infant is below the lower end of the range for the mother's LADD. On a mass basis the cumulative dose to the infant through breast feeding accounts for between 4 to 12 percent of the lifetime dose (assuming background levels).

Although procedures exist for estimating an infant's exposure to a contaminant through ingestion of breast milk, the health consequences of such exposures are not easily assessed. For 2,3,7,8-TCDD and other cancer causing agents with similar lipophilic properties, the typical approach would be to use the LADD to calculate an individual lifetime cancer risk attributable to the infant's exposure. This risk could be considered separately or in addition to other lifetime exposures. The latter approach would increase lifetime cancer risk estimates for 2,3,7,8-TCDD by about 10 percent over that of an adult without such exposures during infancy. However, for

2,3,7,8-TCDD and other similar chemicals, the health effects associated with elevated exposures during the first year of life are not well characterized. It is possible that noncancer health effects could be of much greater concern than cancer. Given the uncertainty in how to interpret the health effects attributable to an infant's exposure to contaminants through ingestion of breast milk, exposures from breast milk are not included as part of the screening analysis.

The remainder of this section is organized as follows. As indicated in the previous text box, the tables for characterizing risk from indirect exposures for the four exposure scenarios are given in Section 6.1 through Section 6.4. Characterizing risk from direct inhalation exposures is discussed for all four exposure scenarios in Section 6.5, as indicated in the text box. Finally, characterizing overall cancer risk from both direct and indirect exposures is discussed in Section 6.6.

Sections 6.1 through 6.4	**Indirect Exposures**
Section 6.5	**Direct Inhalation Exposures**
Section 6.6	**Overall Direct and Indirect Cancer Risk**

6.1 Subsistence Farmer Scenario

This section provides the equations needed for characterizing risk from indirect exposures for the subsistence farmer scenario. The following equation tables are included:

Table 6.1.1. Soil Intake for Subsistence Farmer Scenario
Table 6.1.2. Above-Ground and Root Vegetable Intake for Subsistence Farmer Scenario
Table 6.1.3. Beef and Milk Intake for Subsistence Farmer Scenario
Table 6.1.4. Total Daily Intake for Subsistence Farmer Scenario
Table 6.1.5. Cancer Risk for Individual Chemicals for Subsistence Farmer Scenario: Carcinogens
Table 6.1.6. Hazard Quotient for Individual Chemicals for Subsistence Farmer Scenario: NonCarcinogens
Table 6.1.7. Total Cancer Risk for Subsistence Farmer Scenario: Carcinogens
Table 6.1.8. Hazard Index for Liver Effects for Subsistence Farmer Scenario: NonCarcinogens
Table 6.1.9. Hazard Index for Neurotoxic Effects for Subsistence Farmer Scenario: NonCarcinogens

Table 6.1.1. Soil Intake for Subsistence Farmer Scenario

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis(2-ethylhexyl)phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene Di(n)octyl phthalate	Hexachlorobenzene Mercury Nitrobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$I_{soil} = Sc \cdot CR_{soil} \cdot F_{soil}$$

Parameter	Description	Value
I_{soil}	Daily intake of contaminant from soil (mg/day)	
Sc	Soil concentration (mg/kg)	calculated (see Table 4.1.1)
CR_{soil}	Consumption rate of soil (kg/day)	0.0001
F_{soil}	Fraction of consumed soil contaminated (unitless)	1

Table 6.1.2. Above-Ground and Root Vegetable Intake for Subsistence Farmer Scenario

Chemicals

Arsenic
Beryllium
Benzo(a)pyrene toxicity equivalents
Bis(2-ethylhexyl)phthalate
1,3-Dinitro benzene
2,4-Dinitro toluene
2,6-Dinitro toluene
Di(n)octyl phthalate

Hexachlorobenzene
Mercury
Nitrobenzene
total PCBs
Pentachloronitrobenzene
Pentachlorophenol
2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$I_{ag} = (Pd + Pv) \cdot CR_{ag} \cdot F_{ag}$$

$$I_{bg} = Pr_{bg} \cdot CR_{bg} \cdot F_{bg}$$

Parameter	Description	Value
I_{ag}	Daily intake of contaminant from above-ground vegetables (mg/day)	
Pd	Concentration in above-ground vegetables due to deposition (mg/kg)	calculated (see Table 4.2.1)
Pv	Concentration in above-ground vegetables due to air-to-plant transfer (mg/kg)	calculated (see Table 4.2.2)
CR_{ag}	Consumption rate of above-ground vegetables (kg/day)	0.024
F_{ag}	Fraction of above-ground vegetables contaminated (unitless)	0.95
I_{bg}	Daily intake of contaminant from root vegetables (mg/day)	
Pr_{bg}	Concentration in root vegetables (mg/kg)	calculated (see Table 4.3.2)
CR_{bg}	Consumption rate of root vegetables (kg/day)	0.0063
F_{bg}	Fraction of root vegetables contaminated (unitless)	0.95

Table 6.1.3. Beef and Milk Intake for Subsistence Farmer Scenario

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene Hexachlorobenzene	Mercury Nitrobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$I_{beef} = A_{beef} \cdot CR_{beef} \cdot F_{beef}$$

$$I_{milk} = A_{milk} \cdot CR_{milk} \cdot F_{milk}$$

Parameter	Description	Value
I_{beef}	Daily intake of contaminant from beef (mg/day)	
A_{beef}	Concentration in beef (mg/kg)	calculated (see Table 4.4.4)
CR_{beef}	Consumption rate of beef (kg/day)	0.1
F_{beef}	Fraction of beef contaminated (unitless)	0.44
I_{milk}	Daily intake of contaminant from milk (mg/day)	
A_{milk}	Concentration in milk (mg/kg)	calculated (see Table 4.4.5)
CR_{milk}	Consumption rate of milk (kg/day)	0.3
F_{milk}	Fraction of milk contaminated (unitless)	0.40

Table 6.1.4. Total Daily Intake for Subsistence Farmer Scenario

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis(2-ethylhexyl)phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene Di(n)octyl phthalate	Hexachlorobenzene Mercury Nitrobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$I = I_{soil} + I_{ag} + I_{bg} + I_{beef} + I_{milk}$$

Parameter	Description	Value
I	Total daily intake of contaminant (mg/day)	
I_{soil}	Daily intake of contaminant from soil (mg/day)	calculated (see Table 6.1.1)
I_{ag}	Daily intake of contaminant from above-ground vegetables (mg/day)	calculated (see Table 6.1.2)
I_{bg}	Daily intake of contaminant from root vegetables (mg/day)	calculated (see Table 6.1.2)
I_{beef}	Daily intake of contaminant from beef (mg/day)	calculated (see Table 6.1.3)
I_{milk}	Daily intake of contaminant from milk (mg/day)	calculated (see Table 6.1.3)

Table 6.1.5. Cancer Risk for Individual Chemicals for Subsistence Farmer Scenario
Carcinogens

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis(2-ethylhexyl) phthalate 2,4-Dinitro toluene 2,6-Dinitro toluene	Hexachlorobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$Cancer\ Risk = \frac{I \cdot ED \cdot EF \cdot CSF}{BW \cdot AT \cdot 365}$$

Parameter	Description	Value
Cancer Risk	Individual lifetime cancer risk (unitless)	
I	Total daily intake of contaminant (mg/day)	calculated (see Table 6.1.4)
ED	Exposure duration (yr)	40
EF	Exposure frequency (day/yr)	350
BW	Body weight (kg)	70
AT	Averaging time (yr)	70
365	Units conversion factor (day/yr)	
CSF	Oral cancer slope factor (per mg/kg/day)	chemical-specific

Table 6.1.6. Hazard Quotient for Individual Chemicals for Subsistence Farmer Scenario NonCarcinogens

Chemicals	
Arsenic Beryllium Bis (2-ethylhexyl) phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene	Di(n)octyl phthalate Hexachlorobenzene Mercury Nitrobenzene Pentachloronitrobenzene Pentachlorophenol

Equation

$$HQ = \frac{I}{BW \cdot RfD}$$

Parameter	Description	Value
HQ	Hazard quotient (unitless)	
I	Total daily intake of contaminant (mg/day)	calculated (see Table 6.1.4)
BW	Body weight (kg)	70
RfD	Reference Dose (mg/kg/day)	chemical-specific

Table 6.1.7. Total Cancer Risk for Subsistence Farmer Scenario Carcinogens

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis(2-ethylhexyl) phthalate 2,4-Dinitro toluene 2,6-Dinitro toluene	Hexachlorobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$Total\ Cancer\ Risk = \sum_i Cancer\ Risk_i$$

Parameter	Description	Value
Total Cancer Risk	Total individual lifetime cancer risk for all chemicals (unitless)	
Cancer Risk$_i$	Individual lifetime cancer risk for chemical carcinogen i (unitless)	calculated (see Table 6.1.5)

Table 6.1.8. Hazard Index for Liver Effects for Subsistence Farmer Scenario NonCarcinogens

Chemicals	
Bis(2-ethylhexyl phthalate) Di(n)octyl phthalate Hexachlorobenzene	Pentachloronitrobenzene Pentachlorophenol

Equation

$$HI_{liver} = \sum_{i} HQ_{i}$$

Parameter	Description	Value
HI_{liver}	Hazard index for liver effects (unitless)	
HQ_i	Hazard quotient for chemical i with liver effects (unitless)	calculated (see Table 6.1.6)

Table 6.1.9. Hazard Index for Neurotoxic Effects for Subsistence Farmer Scenario
NonCarcinogens

Chemicals	
2,4-Dinitro toluene 2,6-Dinitro toluene	Mercury

Equation

$$HI_{neurotoxin} = \sum_{i} HQ_{i}$$

Parameter	Description	Value
$HI_{neurotoxin}$	Hazard index for neurotoxic effects (unitless)	
HQ_i	Hazard quotient for chemical i with neurotoxic effects (unitless)	calculated (see Table 6.1.6)

6.2 Subsistence Fisher Scenario

This section provides the equations needed for characterizing risk from indirect exposures for the subsistence fisher scenario. The following equation tables are included:

Table 6.2.1. Soil Intake for Subsistence Fisher Scenario
Table 6.2.2. Above-Ground and Root Vegetable Intake for Subsistence Fisher Scenario
Table 6.2.3. Fish Intake for Subsistence Fisher Scenario
Table 6.2.4. Total Daily Intake for Subsistence Fisher Scenario
Table 6.2.5. Cancer Risk for Individual Chemicals for Subsistence Fisher Scenario: Carcinogens
Table 6.2.6. Hazard Quotient for Individual Chemicals for Subsistence Fisher Scenario: NonCarcinogens
Table 6.2.7. Total Cancer Risk for Subsistence Fisher Scenario: Carcinogens
Table 6.2.8. Hazard Index for Liver Effects for Subsistence Fisher Scenario: NonCarcinogens
Table 6.2.9. Hazard Index for Neurotoxic Effects for Subsistence Fisher Scenario: NonCarcinogens

Table 6.2.1. Soil Intake for Subsistence Fisher Scenario

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis(2-ethylhexyl)phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene Di(n)octyl phthalate	Hexachlorobenzene Mercury Nitrobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$I_{soil} = Sc \cdot CR_{soil} \cdot F_{soil}$$

Parameter	Description	Value
I_{soil}	Daily intake of contaminant from soil (mg/day)	
Sc	Soil concentration (mg/kg)	calculated (see Table 4.1.1)
CR_{soil}	Consumption rate of soil (kg/day)	0.0001
F_{soil}	Fraction of consumed soil contaminated (unitless)	1

Table 6.2.2. Above-Ground and Root Vegetable Intake for Subsistence Fisher Scenario

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis(2-ethylhexyl)phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene Di(n)octyl phthalate	Hexachlorobenzene Mercury Nitrobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$I_{ag} = (Pd + Pv) \cdot CR_{ag} \cdot F_{ag}$$

$$I_{bg} = Pr_{bg} \cdot CR_{bg} \cdot F_{bg}$$

Parameter	Description	Value
I_{ag}	Daily intake of contaminant from above-ground vegetables (mg/day)	
Pd	Concentration in above-ground vegetables due to deposition (mg/kg)	calculated (see Table 4.2.1)
Pv	Concentration in above-ground vegetables due to air-to-plant transfer (mg/kg)	calculated (see Table 4.2.2)
CR_{ag}	Consumption rate of above-ground vegetables (kg/day)	0.024
F_{ag}	Fraction of above-ground vegetables contaminated (unitless)	0.25
I_{bg}	Daily intake of contaminant from root vegetables (mg/day)	
Pr_{bg}	Concentration in root vegetables (mg/kg)	calculated (see Table 4.3.2)
CR_{bg}	Consumption rate of root vegetables (kg/day)	0.0063
F_{bg}	Fraction of root vegetables contaminated (unitless)	0.25

Table 6.2.3. Fish Intake for Subsistence Fisher Scenario

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis (2-ethylhexyl) phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene	Di(n)octyl phthalate Hexachlorobenzene Methyl mercury Nitrobenzene total PCBs Pentachloronitrobenzene 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$I_{fish} = C_{fish} \cdot CR_{fish} \cdot F_{fish}$$

Parameter	Description	Value
I_{fish}	Daily intake of contaminant from fish (mg/day)	
C_{fish}	Fish concentration (mg/kg)	calculated (see Tables 4.5.14, 4.5.15, 4.5.16)
CR_{fish}	Consumption rate of fish (kg/day)	0.140
F_{fish}	Fraction of fish contaminated (unitless)	1

Table 6.2.4. Total Daily Intake for Subsistence Fisher Scenario

Chemicals

- Arsenic
- Beryllium
- Benzo(a)pyrene toxicity equivalents
- Bis (2-ethylhexyl) phthalate
- 1,3-Dinitro benzene
- 2,4-Dinitro toluene
- 2,6-Dinitro toluene
- Di(n)octyl phthalate
- Hexachlorobenzene
- Mercury/Methyl mercury
- Nitrobenzene
- total PCBs
- Pentachloronitrobenzene
- Pentachlorophenol
- 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$I = I_{soil} + I_{ag} + I_{bg} + I_{fish}$$

Parameter	Description	Value
I	Total daily intake of contaminant (mg/day)	
I_{soil}	Daily intake of contaminant from soil (mg/day)	calculated (see Table 6.2.1)
I_{ag}	Daily intake of contaminant from above-ground vegetables (mg/day)	calculated (see Table 6.2.2)
I_{bg}	Daily intake of contaminant from root vegetables (mg/day)	calculated (see Table 6.2.2)
I_{fish}	Daily intake of contaminant from fish (mg/day)	calculated (see Table 6.2.3)

Table 6.2.5. Cancer Risk for Individual Chemicals for Subsistence Fisher Scenario
Carcinogens

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis(2-ethylhexyl) phthalate 2,4-Dinitro toluene 2,6-Dinitro toluene	Hexachlorobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$Cancer\ Risk = \frac{I \cdot ED \cdot EF \cdot CSF}{BW \cdot AT \cdot 365}$$

Parameter	Description	Value
Cancer Risk	Individual lifetime cancer risk (unitless)	
I	Total daily intake of contaminant (mg/day)	calculated (see Table 6.2.4)
ED	Exposure duration (yr)	30
EF	Exposure frequency (day/yr)	350
BW	Body weight (kg)	70
AT	Averaging time (yr)	70
365	Units conversion factor (day/yr)	
CSF	Oral cancer slope factor (per mg/kg/day)	chemical-specific

Table 6.2.6. Hazard Quotient for Individual Chemicals for Subsistence Fisher Scenario NonCarcinogens

Chemicals	
Arsenic Beryllium Bis (2-ethylhexyl) phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene	Di(n)octyl phthalate Hexachlorobenzene Mercury/Methyl mercury Nitrobenzene Pentachloronitrobenzene Pentachlorophenol

Equation

$$HQ = \frac{I}{BW \cdot RfD}$$

Parameter	Description	Value
HQ	Hazard quotient (unitless)	
I	Total daily intake of contaminant (mg/day)	calculated (see Table 6.2.4)
BW	Body weight (kg)	70
RfD	Reference Dose (mg/kg/day)	chemical-specific

Table 6.2.7. Total Cancer Risk for Subsistence Fisher Scenario Carcinogens

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis(2-ethylhexyl) phthalate 2,4-Dinitro toluene 2,6-Dinitro toluene	Hexachlorobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$\text{Total Cancer Risk} = \sum_i \text{Cancer Risk}_i$$

Parameter	Description	Value
Total Cancer Risk	Total individual lifetime cancer risk for all chemicals (unitless)	
Cancer Risk_i	Individual lifetime cancer risk for chemical carcinogen i (unitless)	calculated (see Table 6.2.5)

Table 6.2.8. Hazard Index for Liver Effects for Subsistence Fisher Scenario NonCarcinogens

Chemicals	
Bis(2-ethylhexyl phthalate) Di(n)octyl phthalate Hexachlorobenzene	Pentachloronitrobenzene Pentachlorophenol

Equation

$$HI_{liver} = \sum_{i} HQ_{i}$$

Parameter	Description	Value
HI_{liver}	Hazard index for liver effects (unitless)	
HQ_i	Hazard quotient for chemical i with liver effects (unitless)	calculated (see Table 6.2.6)

Table 6.2.9. Hazard Index for Neurotoxic Effects for Subsistence Fisher Scenario
NonCarcinogens

Chemicals	
2,4-Dinitro toluene 2,6-Dinitro toluene	Mercury/Methyl mercury

Equation

$$HI_{neurotoxin} = \sum_{i} HQ_{i}$$

Parameter	Description	Value
$HI_{neurotoxin}$	Hazard index for neurotoxic effects (unitless)	
HQ_i	Hazard quotient for chemical i with neurotoxic effects (unitless)	calculated (see Table 6.2.6)

6.3 Adult Resident Scenario

This section provides the equations needed for characterizing risk from indirect exposures for the adult resident scenario. The following equation tables are included:

Table 6.3.1. Soil Intake for Adult Resident Scenario

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis(2-ethylhexyl)phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene Di(n)octyl phthalate	Hexachlorobenzene Mercury Nitrobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$I_{soil} = Sc \cdot CR_{soil} \cdot F_{soil}$$

Parameter	Description	Value
I_{soil}	Daily intake of contaminant from soil (mg/day)	
Sc	Soil concentration (mg/kg)	calculated (see Table 4.1.1)
CR_{soil}	Consumption rate of soil (kg/day)	0.0001
F_{soil}	Fraction of consumed soil contaminated (unitless)	1

Table 6.3.2. Above-Ground and Root Vegetable Intake for Adult Resident Scenario

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis(2-ethylhexyl)phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene Di(n)octyl phthalate	Hexachlorobenzene Mercury Nitrobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$I_{ag} = (Pd + Pv) \cdot CR_{ag} \cdot F_{ag}$$

$$I_{bg} = Pr_{bg} \cdot CR_{bg} \cdot F_{bg}$$

Parameter	Description	Value
I_{ag}	Daily intake of contaminant from above-ground vegetables (mg/day)	
Pd	Concentration in above-ground vegetables due to deposition (mg/kg)	calculated (see Table 4.2.1)
Pv	Concentration in above-ground vegetables due to air-to-plant transfer (mg/kg)	calculated (see Table 4.2.2)
CR_{ag}	Consumption rate of above-ground vegetables (kg/day)	0.024
F_{ag}	Fraction of above-ground vegetables contaminated (unitless)	0.25
I_{bg}	Daily intake of contaminant from root vegetables (mg/day)	
Pr_{bg}	Concentration in root vegetables (mg/kg)	calculated (see Table 4.3.2)
CR_{bg}	Consumption rate of root vegetables (kg/day)	0.0063
F_{bg}	Fraction of root vegetables contaminated (unitless)	0.25

Table 6.3.3. Total Daily Intake for Adult Resident Scenario

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis(2-ethylhexyl)phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene Di(n)octyl phthalate	Hexachlorobenzene Mercury Nitrobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$I = I_{soil} + I_{ag} + I_{bg}$$

Parameter	Description	Value
I	Total daily intake of contaminant (mg/day)	
I_{soil}	Daily intake of contaminant from soil (mg/day)	calculated (see Table 6.3.1)
I_{ag}	Daily intake of contaminant from above-ground vegetables (mg/day)	calculated (see Table 6.3.2)
I_{bg}	Daily intake of contaminant from root vegetables (mg/day)	calculated (see Table 6.3.2)

Table 6.3.4. Cancer Risk for Individual Chemicals for Adult Resident Scenario Carcinogens

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis(2-ethylhexyl) phthalate 2,4-Dinitro toluene 2,6-Dinitro toluene	Hexachlorobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$Cancer\ Risk = \frac{I \cdot ED \cdot EF \cdot CSF}{BW \cdot AT \cdot 365}$$

Parameter	Description	Value
Cancer Risk	Individual lifetime cancer risk (unitless)	
I	Total daily intake of contaminant (mg/day)	calculated (see Table 6.3.3)
ED	Exposure duration (yr)	30
EF	Exposure frequency (day/yr)	350
BW	Body weight (kg)	70
AT	Averaging time (yr)	70
365	Units conversion factor (day/yr)	
CSF	Oral cancer slope factor (per mg/kg/day)	chemical-specific

Table 6.3.5. Hazard Quotient for Individual Chemicals for Adult Resident Scenario NonCarcinogens

Chemicals	
Arsenic Beryllium Bis (2-ethylhexyl) phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene	Di(n)octyl phthalate Hexachlorobenzene Mercury Nitrobenzene Pentachloronitrobenzene Pentachlorophenol

Equation

$$HQ = \frac{I}{BW \cdot RfD}$$

Parameter	Description	Value
HQ	Hazard quotient (unitless)	
I	Total daily intake of contaminant (mg/day)	calculated (see Table 6.3.3)
BW	Body weight (kg)	70
RfD	Reference Dose (mg/kg/day)	chemical-specific

Table 6.3.6. Total Cancer Risk for Adult Resident Scenario Carcinogens

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis(2-ethylhexyl) phthalate 2,4-Dinitro toluene 2,6-Dinitro toluene	Hexachlorobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2;3,7,8-TCDDioxin toxicity equivalents

Equation

$$Total\ Cancer\ Risk = \sum_i Cancer\ Risk_i$$

Parameter	Description	Value
Total Cancer Risk	Total individual lifetime cancer risk for all chemicals (unitless)	
Cancer $Risk_i$	Individual lifetime cancer risk for chemical carcinogen i (unitless)	calculated (see Table 6.3.4)

Table 6.3.7. Hazard Index for Liver Effects for Adult Resident Scenario NonCarcinogens

Chemicals	
Bis(2-ethylhexyl phthalate) Di(n)octyl phthalate Hexachlorobenzene	Pentachloronitrobenzene Pentachlorophenol

Equation

$$HI_{liver} = \sum_{i} HQ_{i}$$

Parameter	Description	Value
HI_{liver}	Hazard index for liver effects (unitless)	
HQ_i	Hazard quotient for chemical i with liver effects (unitless)	calculated (see Table 6.3.5)

Table 6.3.8. Hazard Index for Neurotoxic Effects for Adult Resident Scenario NonCarcinogens

Chemicals	
2,4-Dinitro toluene 2,6-Dinitro toluene	Mercury

Equation

$$HI_{neurotoxin} = \sum_{i} HQ_{i}$$

Parameter	Description	Value
$HI_{neurotoxin}$	Hazard index for neurotoxic effects (unitless)	
HQ_i	Hazard quotient for chemical i with neurotoxic effects (unitless)	calculated (see Table 6.3.5)

6.4 Child Resident Scenario

This section provides the equations needed for characterizing risk from indirect exposures for the child resident scenario. The following equation tables are included:

Table 6.4.1.	Soil Intake for Child Resident Scenario
Table 6.4.2.	Above-Ground and Root Vegetable Intake for Child Resident Scenario
Table 6.4.3.	Total Daily Intake for Child Resident Scenario
Table 6.4.4.	Cancer Risk for Individual Chemicals for Child Resident Scenario: Carcinogens
Table 6.4.5.	Hazard Quotient for Individual Chemicals for Child Resident Scenario: NonCarcinogens
Table 6.4.6.	Total Cancer Risk for Child Resident Scenario: Carcinogens
Table 6.4.7.	Hazard Index for Liver Effects for Child Resident Scenario: NonCarcinogens
Table 6.4.8.	Hazard Index for Neurotoxic Effects for Child Resident Scenario: NonCarcinogens

Table 6.4.1. Soil Intake for Child Resident Scenario

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis(2-ethylhexyl)phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene Di(n)octyl phthalate	Hexachlorobenzene Mercury Nitrobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$I_{soil} = Sc \cdot CR_{soil} \cdot F_{soil}$$

Parameter	Description	Value
I_{soil}	Daily intake of contaminant from soil (mg/day)	
Sc	Soil concentration (mg/kg)	calculated (see Table 4.1.1)
CR_{soil}	Consumption rate of soil (kg/day)	0.0002
F_{soil}	Fraction of consumed soil contaminated (unitless)	1

Table 6.4.2. Above-Ground and Root Vegetable Intake for Child Resident Scenario

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis(2-ethylhexyl)phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene Di(n)octyl phthalate	Hexachlorobenzene Mercury Nitrobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$I_{ag} = (Pd + Pv) \cdot CR_{ag} \cdot F_{ag}$$

$$I_{bg} = Pr_{bg} \cdot CR_{bg} \cdot F_{bg}$$

Parameter	Description	Value
I_{ag}	Daily intake of contaminant from above-ground vegetables (mg/day)	
Pd	Concentration in above-ground vegetables due to deposition (mg/kg)	calculated (see Table 4.2.1)
Pv	Concentration in above-ground vegetables due to air-to-plant transfer (mg/kg)	calculated (see Table 4.2.2)
CR_{ag}	Consumption rate of above-ground vegetables (kg/day)	0.005
F_{ag}	Fraction of above-ground vegetables contaminated (unitless)	0.25
I_{bg}	Daily intake of contaminant from root vegetables (mg/day)	
Pr_{bg}	Concentration in root vegetables (mg/kg)	calculated (see Table 4.3.2)
CR_{bg}	Consumption rate of root vegetables (kg/day)	0.0014
F_{bg}	Fraction of root vegetables contaminated (unitless)	0.25

Table 6.4.3. Total Daily Intake for Child Resident Scenario

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis(2-ethylhexyl)phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene Di(n)octyl phthalate	Hexachlorobenzene Mercury Nitrobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$I = I_{soil} + I_{ag} + I_{bg}$$

Parameter	Description	Value
I	Total daily intake of contaminant (mg/day)	
I_{soil}	Daily intake of contaminant from soil (mg/day)	calculated (see Table 6.4.1)
I_{ag}	Daily intake of contaminant from above-ground vegetables (mg/day)	calculated (see Table 6.4.2)
I_{bg}	Daily intake of contaminant from root vegetables (mg/day)	calculated (see Table 6.4.2)

Table 6.4.4. Cancer Risk for Individual Chemicals for Child Resident Scenario Carcinogens

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis(2-ethylhexyl) phthalate 2,4-Dinitro toluene 2,6-Dinitro toluene	Hexachlorobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$\mathit{Cancer\ Risk} = \frac{I \cdot ED \cdot EF \cdot CSF}{BW \cdot AT \cdot 365}$$

Parameter	Description	Value
Cancer Risk	Individual lifetime cancer risk (unitless)	
I	Total daily intake of contaminant (mg/day)	calculated (see Table 6.4.3)
ED	Exposure duration (yr)	6
EF	Exposure frequency (day/yr)	350
BW	Body weight (kg)	15
AT	Averaging time (yr)	70
365	Units conversion factor (day/yr)	
CSF	Oral cancer slope factor (per mg/kg/day)	chemical-specific

Table 6.4.5. Hazard Quotient for Individual Chemicals for Child Resident Scenario NonCarcinogens

Chemicals	
Arsenic Beryllium Bis (2-ethylhexyl) phthalate 1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene	Di(n)octyl phthalate Hexachlorobenzene Mercury Nitrobenzene Pentachloronitrobenzene Pentachlorophenol

Equation

$$HQ = \frac{I}{BW \cdot RfD}$$

Parameter	Description	Value
HQ	Hazard quotient (unitless)	
I	Total daily intake of contaminant (mg/day)	calculated (see Table 6.4.3)
BW	Body weight (kg)	15
RfD	Reference Dose (mg/kg/day)	chemical-specific

Table 6.4.6. Total Cancer Risk for Child Resident Scenario Carcinogens

Chemicals	
Arsenic Beryllium Benzo(a)pyrene toxicity equivalents Bis(2-ethylhexyl) phthalate 2,4-Dinitro toluene 2,6-Dinitro toluene	Hexachlorobenzene total PCBs Pentachloronitrobenzene Pentachlorophenol 2,3,7,8-TCDDioxin toxicity equivalents

Equation

$$Total\ Cancer\ Risk = \sum_{i} Cancer\ Risk_{i}$$

Parameter	Description	Value
Total Cancer Risk	Total individual lifetime cancer risk for all chemicals (unitless)	
Cancer $Risk_i$	Individual lifetime cancer risk for chemical carcinogen i (unitless)	calculated (see Table 6.4.4)

Table 6.4.7. Hazard Index for Liver Effects for Child Resident Scenario NonCarcinogens

Chemicals	
Bis(2-ethylhexyl phthalate) Di(n)octyl phthalate Hexachlorobenzene	Pentachloronitrobenzene Pentachlorophenol

Equation

$$HI_{liver} = \sum_{i} HQ_{i}$$

Parameter	Description	Value
HI_{liver}	Hazard index for liver effects (unitless)	
HQ_i	Hazard quotient for chemical *i with liver effects* (unitless)	calculated (see Table 6.4.5)

Table 6.4.8. Hazard Index for Neurotoxic Effects for Child Resident Scenario NonCarcinogens

Chemicals	
2,4-Dinitro toluene 2,6-Dinitro toluene	Mercury

Equation

$$HI_{neurotoxin} = \sum_{i} HQ_{i}$$

Parameter	Description	Value
$HI_{neurotoxin}$	Hazard index for neurotoxic effects (unitless)	
HQ_i	Hazard quotient for chemical i with neurotoxic effects (unitless)	calculated (see Table 6.4.5)

6.5 Direct Inhalation Exposures

Characterization of risks from direct inhalation exposures is necessary to complete the screening analysis. Risks should be characterized from all chemicals emitted by the combustion source that have inhalation health criteria or benchmarks. The Implementation Guidance provides a list of chemicals in combustion emissions that should be addressed as part of the screening analysis. Although a number of the chemical compounds identified in the Implementation Guidance do not have appropriate health criteria or benchmarks for assessing inhalation exposures, all chemical compounds that do have unit risk factors (URF's), carcinogenic slope factors (CSF's), or reference concentrations (RfC's) in IRIS[6] or HEAST[7] should be included in the screening analysis.

The excess lifetime individual cancer risk from direct inhalation of a chemical carcinogen is calculated from the unit risk factor (URF) for each exposure scenario as follows:

$$Cancer\ \ Risk(inh)_{i,j} = C(air)_{i,j} \cdot URF(inh)_i \tag{6-1}$$

where:

$\text{Cancer Risk(inh)}_{h,i,j}$ = Excess lifetime cancer risk via inhalation (unitless), chemical i (i=1..n), exposure scenario j (j=1..4)
$C_{air,i,j}$ = Concentration in air (μg/m^3, from COMPDEP), chemical i (i=1..n), exposure scenario j (j=1..4)
URF(inh)_i = Inhalation unit risk factor (per μg/m^3), chemical i (i=1..n)

Alternatively, if a carcinogenic slope factor (CSF) is available for the chemical, the lifetime individual cancer risk is calculated from the average daily intake via inhalation (ADI). The average daily intake via inhalation is calculated for each exposure scenario as follows:

$$ADI(inh)_{i,j} = \frac{C(air)_{i,j} \cdot IR_j \cdot ET \cdot EF \cdot ED_j \cdot 0.001}{BW_j \cdot AT} \tag{6-2}$$

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[6] Integrated Risk Information System on-line database, as described in the Federal Register of February 25, 1993 (58 FR 11490).

[7] Health Effects Assessment Summary Tables, Annual Update and Supplements thereto (U.S. EPA, 1993d, 1993e, and 1993f).

where:

$ADI(inh)_{i,j}$ = Average daily intake via inhalation (mg/kg/day), chemical i (i=1..m), exposure scenario j (j=1..4)
$C(air)_{i,j}$ = Ambient air concentration ($\mu g/m^3$, from COMPDEP), chemical i (i=1..m), exposure scenario j (j=1..4)
IR_j = Inhalation rate (m^3/hr), exposure scenario j (j=1..4)
ET = Exposure time (24 hours/day)
EF = Exposure frequency (350 days/yr)
ED_j = Exposure duration (years), exposure scenario j (j=1..4)
BW_j = Body weight (kg), exposure scenario j (j=1..4)
AT = Averaging time (25,550 days)
0.001 = Units conversion factor

The averaging time for the ADI is taken as a lifetime (i.e., 70 years). The exposure parameter values for Equation 6-2 that depend on the particular exposure scenario are given in Table 6.5.

Table 6.5. Exposure Parameter Values for Average Daily Intake via Inhalation

Exposure Parameter	Exposure Scenario			
	Subsistence Farmer	Subsistence Fisher	Adult Resident	Child Resident
Inhalation Rate (m^3/hr)	1.0	1.0	1.0	0.2
Exposure Duration (years)	40	30	30	6
Body Weight (kg)	70	70	70	15

The excess lifetime individual cancer risk is then calculated from the carcinogenic slope factor (CSF) and the average daily intake via inhalation. For each exposure scenario:

$$Cancer\ Risk(inh)_{i,j} = ADI(inh)_{i,j} \cdot CSF(inh)_i \qquad 6\text{-}3$$

where:

$Cancer\ Risk(inh)_{i,j}$ = Excess lifetime cancer risk via inhalation (unitless), chemical i (i=1..m), exposure scenario j (j=1..4)
$ADI(inh)_{i,j}$ = Average daily intake via inhalation (mg/kg/day), chemical i (i=1..m), exposure scenario j (j=1..4)
$CSF(inh)_i$ = Inhalation carcinogenic slope factor (per mg/kg/day), chemical i (i=1..m)

The total cancer risk to the individual via inhalation is estimated by summing the lifetime individual cancer risk for all chemicals that are carcinogenic via the inhalation route of exposure:

$$Total\ Cancer\ Risk(inh)_j = \sum_i Cancer\ Risk(inh)_{i,j} \qquad 6\text{-}4$$

where:

Total Cancer Risk(inh)$_j$ = Total excess lifetime cancer risk via inhalation (unitless), exposure scenario j (j=1..4)
Cancer Risk(inh)$_{i,j}$ = Excess lifetime cancer risk via inhalation (unitless), chemical i (1=1..m+n), exposure scenario j (j=1..4)

The hazard quotient for inhalation exposures to chemicals which have noncancer health effects is calculated for each exposure scenario as follows:

$$HQ(inh)_{i,j} = \frac{C(air)_{i,j}}{RfC_i} \cdot 10^{-3} \qquad 6\text{-}5$$

where:

HQ(inh)$_{i,j}$ = Hazard quotient via inhalation (unitless), chemical i (i=1..l), exposure scenario j (j=1..4)
C(air)$_{i,j}$ = Concentration in air (μg/m^3, from COMPDEP), chemical i (i=1..l), exposure scenario j (j=1..4)
RfC$_i$ = Reference concentration (mg/m^3), chemical i (i=1..l)
10^{-3} = Units conversion factor (mg/μg)

For the screening analysis, the hazard quotients for inhalation exposures to chemicals that affect the same target organ are added together to obtain a hazard index for the target organ. This is done for each exposure scenario as follows:

$$HI(inh)_{j,k} = \sum_i HQ(inh)_{i,j,k} \qquad 6\text{-}6$$

where:

HI(inh)$_{j,k}$ = Hazard index via inhalation (unitless) for target organ k (k=1..h), exposure scenario j (j=1..4)
HQ(inh)$_{i,j,k}$ = Hazard quotient via inhalation (unitless) for target organ k (k=1..h), chemical i (i=1..l), exposure scenario j (j=1..4)

Section 6.6 Overall Direct and Indirect Cancer Risk

To determine the overall carcinogenic risk from all exposure pathways, both direct inhalation and indirect exposure pathways, the total cancer risks for the indirect pathways (as calculated for each exposure scenario in Table 6.1.7, Table 6.2.7, Table 6.3.7, and Table 6.4.7) are added to the total cancer risk via inhalation. For each exposure scenario:

$$\textit{Overall Cancer Risk}_j = \textit{Total Cancer Risk(inh)}_j + \textit{Total Cancer Risk(oral)}_j \qquad 6\text{-}7$$

where:

Overall Cancer Risk$_j$ = Overall excess lifetime cancer risk via all routes of exposure (unitless), exposure scenario j (j=1..4)

Total Cancer Risk(inh)$_j$ = Total excess lifetime cancer risk via inhalation (unitless, from Equation 6-4) exposure scenario j (j=1..4)

Total Cancer Risk(oral)$_j$ = Total excess lifetime cancer risk via indirect (i.e., oral) exposures (unitless, from Tables 6.x.7), exposure scenario j (x=j=1..4)

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