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North Carolina Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units

Prepared for

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1.0 INTRODUCTION

1.1 Background

On May 18, 1993, the U.S. Environmental Protection Agency Administrator announced a draft National Hazardous Waste Minimization and Combustion Strategy designed to reduce reliance on the combustion of hazardous waste and encourage reduced generation of these wastes. One of the primary goals of the strategy is to ensure that combustion facilities do not pose unacceptable risk to human health and the environment. To implement this strategy, the Agency directed the States and the EPA Regional Offices to evaluate direct and indirect routes of exposure as part of the permit application for all hazardous waste burning incinerators, boilers, and industrial furnaces. To assist the State of North Carolina with its efforts to respond to the Agency's directive, Research Triangle Institute (RTI) has provided technical support to the Division of Waste Management in the development of a protocol intended to assist Resource Conservation and Recovery Act (RCRA) Part B Permit applicants in conducting indirect exposure assessments.

1.2 Purpose

This document presents a protocol that can be used by permit applicants in estimating risks attributable to emissions released from combustion units burning hazardous waste as fuel. The protocol provides for three levels of detail in the analysis depending on a determination by the applicant as to which of the levels is the most appropriate. The approaches presented in this document are not intended to serve as detailed site-specific risk assessment guidance. Rather, the presented guidance is intended to serve as a tool to be used and refined with site-specific information by the permit applicant in consultation with the permit writer. The primary focus of this document is on indirect exposures. However, to characterize the risk from stack emissions, it is necessary to characterize risk from direct inhalation as well. Therefore, the methodology and equations for estimating risk due to direct inhalation are also provided.

By establishing this protocol, the State will be able to promote consistent risk assessments that allow evaluation of risk posed to human health while minimizing costs to the regulated community in terms of both time and resources. The indirect risk assessment will be used to establish safe and reasonable permit limits for the combustion unit. The approach outlined below is comprised of three levels of analysis that will allow the assessor to select the most appropriate level of detail and resource expenditure, ranging from a conservative initial screening evaluation to a more extensive site-specific risk assessment through the use of site-specific information. The three Tiers are:

- *Tier 1 Initial Screening Analysis;*
- *Tier 2 Refined Screening Analysis; and*
- *Tier 3 Site-Specific Assessment.*

The Tier 1 and 2 screening level assessments are intended to give conservative estimates of risk to determine whether a more detailed site-specific Tier 3 assessment is warranted. The resources required to complete the initial screening analysis would be much less than those required for the more detailed analyses. The permit applicant is not required to begin an assessment at Tier 1. Instead, the applicant may opt to forgo Tier 1 and begin the process at Tier 2 or 3. In fact, the Tier 1 assessment is intended primarily for small on-site combustion units that have a limited number of hazardous wastes as feed. This is an inexpensive screening approach that such facilities could use to determine if an investment in more detailed analyses are warranted. It is unlikely that commercial units or large on-site units would conduct a Tier 1 analysis.

The methods specified in this document are consistent with the most current approaches being employed to assess indirect exposures. The primary references used in developing this protocol include the following two documents:

U.S. EPA. 1996. Final Draft - *Risk Assessment Support to the Development of Technical Standards for Emissions from Combustion Units Burning Hazardous Wastes: Background Information Document.* (Internet Address: http://www.epa.gov/epaoswer/hazwaste/combust/cmbust.htm#docs)

U.S. EPA. December 1994a. Revised Draft - *Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes* (referred to henceforth as the *Screening Guidance*). Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.

These two documents were developed from the following documents, which preceded them.

U.S. EPA. April 1994b. Revised Draft - *Implementation Guidance for Conducting Indirect Exposure Analyses at RCRA Combustion Units* (referred to henceforth as the *Implementation Guidance*).

U.S. EPA. 1994c. *Estimating Exposure to Dioxin Exposure to Dioxin-Like Compounds.* Volumes II and III. (referred to henceforth as the *Dioxin Reassessment*). (EPA/600/6-88/005Cb and Cc)

U.S. EPA. January 1990. Interim Final - *Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions* (EPA/600/6-90/003).

U.S. EPA. November 1993. Review Draft - *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions* (referred to henceforth as the *Addendum*).

The procedures specified for conducting the Tier 1 and 2 screening level assessment are based primarily on guidance provided in the *Screening Guidance*, which is included with this protocol as Attachment A. The methodology presented in this document integrates and simplifies site-specific guidance provided in the interim final report *Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions,* its draft *Addendum, and the Dioxin Reassessment.* The procedures specified for the Tier 3 are based primarily on the approach applied in the final draft *Risk Assessment Support to the Development of Technical Standards for Emissions from Combustion Units Burning Hazardous Wastes: Background Information Document.* The methodology applied in this risk assessment document was consistent with the *Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions*, its *Addendum*, and the *Dioxin Reassessment.*

2.0 HOW TO USE THIS DOCUMENT

The purpose of this document is to assist permit applicants in conducting risk assessments for hazardous waste combustion units. The overall approach presented in this document consists of two screening level analyses and one detailed site-specific analysis. As discussed above, the permit applicant may choose to initiate the risk assessment at Tier 1, 2, or 3. The three Tiers are proposed so that a facility applicant has options concerning the investment of resources in conducting risk analyses to support their permit application. The Tier 1 screening analysis relies on many default assumptions and will provide higher estimates of risk than the more refined Tier 2 screening analysis. It is also much less expensive to perform. Similarly, the Tier 2 screening analysis will provide higher estimates of risk than the more refined Tier 3 analysis and is much less expensive to perform than Tier 3. Tier 3 is designed to provide the most accurate estimate of risk among the three Tiers, but requires considerable investment of resources to collect the necessary site specific data. The major difference between the Tier 1 and 2 analyses occurs in the receptor locations and land use data; the emission rates and exposure scenarios remain the same for both levels of analyses. If an applicants selects to perform a Tier 1 or Tier 2 analysis and the risk estimates exceed the following risk criteria, then the next Tier analysis may need to be performed:

1) the total incremental cancer risk from high-end individual exposure to carcinogenic constituents should not exceed $1x10^{-5}$; and

2) the hazard quotient (e.g. the ratio of the total daily intake to the reference dose) for systemic toxicants, non-carcinogens, for the constituent or, when appropriate, the mixture (hazard index), should be less than 0.25.

The permit writer may determine that additional analyses need to be conducted even if these criteria are not exceeded. The need for these additional analyses may arise if it is believed that a facility may pose significant risks to the environment. For example, if it is determined that a facility is located in an area associated with a sensitive ecosystem or a threatened or endangered species, the permit writer may require the permit applicant to conduct an ecological risk assessment.

This document is organized into two major parts with the first part , Sections 1 through 6, designed to be an easy to understand generic workbook. The second part, the appendices, presents the multimedia, multipathway exposure modeling equations, equations for estimating risk, default input parameters, information on the derivation of input parameters, and guidance for obtaining site-specific input parameters as needed. As mentioned above, the first part of the document is comprised of six sections with Section 1 serving as the introduction and this section, Section 2, serving as an overview of the entire document. Section 3 provides an overview of the methods applied under each tier of the assessment and presents a generic check list that can be used by the permit applicant in conducting each tier of the assessment. Section 4 provides guidance on identifying emission sources and constituents of concern and developing constituent-specific emission rates. Section 5 provides detailed discussions on exposure scenarios and pathways to be considered under each tier of the assessment and provides guidance on conducting fate and transport modeling. Section 6 provides guidance on characterizing individual risk and uncertainty. The second part of this document is comprised of four appendices. Appendix A presents chemical-specific properties for those compounds most likely to be emitted and to be of concern. Appendix B presents all of the equations needed to conduct fate and transport modeling under all three tiers. Appendix C presents the equations needed to calculate dose estimates and individual risk estimates. Appendix D identifies the data sources that were used in developing default fate and transport and exposure parameters.

3.0 OVERVIEW OF METHODOLOGY

This section provides a detailed overview of each tier and provides a generic checklist that can be used in conducting each tier of analysis. As discussed above, the permit applicant is not required to begin an analysis at Tier 1; rather, the analysis can be initiated at Tiers 1, 2, or 3. Table 3.1 provides a overview of the tasks to be completed as part of an assessment and highlights the approach that should be undertaken in completing these tasks for each tier of an analysis. The checklist presented in Table 3.2 is intended to facilitate the conducting of an assessment and to ensure consistency in the approach taken in conducting the assessments. Each step identified on the checklist references other sections of the document that provide background information and detailed guidance for completing the task of concern. For example, one of the steps directs the assessor to conduct air dispersion and deposition modeling. Rather than burden the reader with details on how to conduct air quality modeling at that point, Section 5.2.1, which provides detailed guidance on conducting air quality modeling, is referenced.

Table 3.1 Overview of Tiered Risk Assessment Methodology

TASKS	TIER 1	TIER 2	TIER 3
Initial Tier of the Risk Assessment	The permit applicant may choose to initiate the risk assessment at Tier 1, 2, or 3. The three tiers are proposed so that an applicant has options concerning the investment of resources in conducting an analysis.		
Emission Sources (Section 4.1)	Emission sources (i.e., stacks, fugitive emission sources, and operation upsets) of concern will be characterized.		
Constituents of Concern (Section 4.2)	Products of incomplete combustion (PICs) and metal compounds of concern for each facility will need to be identified. PICs will include compounds initially present in feed waste and not destroyed and compounds formed during the combustion process.		
Constituent-specific Emission Estimates (Section 4.3)	High-end emission rates for each constituent of concern including total organic carbon (TOC) will be developed.		
Exposure Scenarios (Sections 5.1.1 thur 5.1.3)			
Exposed Individuals	Four exposure scenarios will be modeled: • adult • child home gardener • subsistence farmer • subsistence fisher		12 general and subpopulation exposure scenarios are to be considered for modeling.
Receptor Locations	Hypothetical worst case location (co-location of maximum points of vapor air concentration and combined deposition of particles).	Actual location of most impacted farms and residences.	Actual locations of the most impacted residences and subsistence farms. Also, average air concentrations and depositions for general population scenarios.
Exposure Pathways	Default fractions contaminated for each item ingested and consumption rates are provided. Site-specific rates can be developed for Tier 2. Exposure through the following pathways: • ingestion of aboveground produce • drinking water ingestion • direct inhalation • beef • soil ingestion • fish ingestion (fisher only) • dairy		Site-specific information is used to develop fractions contaminated and consumption rates. In addition to Tier 1 and 2 pathways, exposure is assumed to occur through: • poultry and egg ingestion • pork ingestion
Air Dispersion and Deposition Modeling with ISCST3 (Section 5.2.1)	ISCST3 is conducted to obtain the following outputs: vapor and particle air concentrations; wet and dry deposition of particles; combined deposition of particles; and wet deposition of vapors. Dry deposition of vapors will be modeled by applying a deposition velocity of 3 cm/s to the air concentration of vapors.		
Media Concentrations (Section 5.2.2)	Using fate and transport equations provided, contaminant concentrations are estimated for the following media: • air • aboveground vegetation • beef • fish • soil • drinking water • dairy		In addition to the Tier 1 and 2 media, contaminant concentrations are estimated for : • pork • poultry • eggs
Risk Estimates (Section 6.1)	• Cancer risk • Noncancer effects • Lead exposures • Infant exposure to Dioxin		
Uncertainty / Limitations (Section 6.2)	• Qualitative assessment • Quantitative (if possible)		

Table 3.2 Generic Checklist for Conducting Risk Analysis

	Tasks to be Completed	✓
1.	Identify Emission Sources (Section 4.1)	
2.	Identify Constituents of Concern (Section 4.2). This step includes determining if impacted surface waterbodies serve as drinking water sources.	
3.	Develop Constituent-Specific Emission Estimates (Section 4.3)	
4.	Define Exposure Scenarios (Sections 5.1.1 through 5.1.3)	
	Exposed individuals	
	Receptor locations	
	Exposure pathways	
	Consumption rates	
	Fraction of consumed media contaminated	
5.	Conduct Air Dispersion and Deposition Modeling with ISCST3 (Section 5.2.1)	
	Define Environmental Setting	
	Obtain and prepare meteorological data	
	Prepare ISCST3 Input Files	
	Areal averaging over watersheds/waterbodies	
	Estimate chemical-specific air concentrations and deposition rates	
6.	Estimate Media Concentrations (Section 5.2.2)	
	Air concentrations for direct inhalation	
	Soil	
	Aboveground produce	
	Beef and dairy	
	Pork	
	Poultry meat and eggs	
	Drinking water and fish	
7.	Estimate Individual Risk (Section 6.1)	
8.	Define Uncertainty and Limitations Associated with Analysis (Section 6.2)	

3.1 Tier 1 Screening Level Assessment

A Tier 1 analysis represents a conservative screening level risk assessment with built in default assumptions and input values. Under this assessment, generic population (e.g., adult resident) and highly exposed subpopulation exposure scenarios (e.g., subsistence farmers, children) will be considered. It will be assumed that the exposed individuals reside at a worst-case hypothetical point of exposure (i.e., the individuals are assumed to reside at a hypothetical location that represents a point where the maximum air concentration and combined deposition are assumed to be co-located). Based on media concentrations and assumptions concerning individual behavior and activity, individual risk estimates will be calculated. If the permit writer determines that the Tier 1 risk estimates exceed the risk criteria outlined in Section 2.0, then a Tier 2 analysis may be warranted.

It is assumed that the Tier 1 approach is most appropriate for small on-site combustion units that burn a small number of highly flammable, non-chlorinated hazardous wastes. Due to the highly conservative nature of this Tier, very few, if any, commercial facilities or large, on-site facilities burning more than a few waste streams could pass the risk criteria using this approach. However, there are a fairly large number of small, on-site combustion units that burn highly flammable, non-chlorinated solvents. This approach was designed for such facilities as a low cost screen to determine if more investment would be needed for the risk analysis portion of their permit application.

3.2 Tier 2 Screening Level Assessment

A Tier 2 analysis represents a more accurate screening level risk assessment than Tier 1 due to the use of some site-specific data. The major difference between the Tier 1 and Tier 2 analyses occurs in the receptor locations. The emission rates and scenario exposure durations remain the same for both levels of analysis. Under Tier 2, site-specific land use information will be collected and used in conjunction with the air modeling results to identify the actual locations of the exposed individuals (e.g., the most impacted residence or farm). The individual risk results from this tier will represent an estimate of high-end risks through the use of subsistence scenarios, high-end exposure durations, and high-end emissions. If the permit writer determines that the Tier 2 risk estimates exceed the risk criteria outlined in Section 2.0, then a Tier 3 site-specific assessment may be warranted. Most large on-site and commercial facilities may prefer to start with a Tier 2 screening level assessment and forgo conducting the Tier 1 assessment. Some facilities may also prefer to forgo the Tier 2 analysis and conduct a Tier 3 analysis.

3.3 Tier 3 Site-Specific Assessment

A Tier 3 assessment is a site-specific analysis designed to present the distribution of individual risks expected in the vicinity of the facility. Under this analysis, detailed site-specific information will be collected in order to make the analysis as accurate as possible given the modeling tools being used. This Tier reduces the level of uncertainty and conservatism in the assessment compared to Tiers 1 and 2. For example, site-specific information can be collected to refine human exposure scenarios and consumption rates to be more representative of activity and behavior patterns found in the impacted areas. The conservative nature of this analysis is accomplished through the use of high-end emissions and exposure durations.

4.0 FACILITY CHARACTERIZATION

This section provides guidance on characterizing the nature and the magnitude of the emissions released from each facility. The characterization will include identifying emission sources, constituents of concern, and developing constituent-specific emission rates.

4.1 Emissions Sources

A facility that burns hazardous wastes in combustion units, may have multiple emission sources on-site that are of potential concern. Typically, the combustion unit stack(s) is associated with the highest level of emissions, and therefore, represents the emission source of primary concern. Other emission sources of potential concern are associated with activities such as storage, blending, and handling of the hazardous waste fuel, as well as storage and handling of combustion residues. During these activities, "fugitive" emissions can be released. Because these emissions are usually small in comparison to the stack emissions, it is believed that the risks posed by these types of emissions will be negligible in comparison to those posed by the stack emissions. Therefore, in most cases, it will not be necessary to quantitatively evaluate risks posed by fugitive emissions. However, it will be necessary to conduct a qualitative assessment to demonstrate that the facility's fugitive emissions are not of concern. The determination of whether a quantitative evaluation is needed will be made by the permit writer based on the qualitative evaluation. If a quantitative evaluation is required, the *Implementation Guidance* cites the following references for estimating fugitive emissions using estimates or measurements of constituent concentrations in the waste feed or in the residual ash.

> *Protocol for Equipment Leak Emission Estimates* (EPA-453/R-93/026) for estimating volatile organic emissions from equipment leaks.
>
> Hazardous Waste TSDF: Background Information for Proposed RCRA Air Emission Standards (EPA-450/3-89-023) for estimating volatile organic emissions from storage tanks and containers.
>
> Hazardous Waste TSDF -Fugitive Particulate Matter Air Emissions Guidance Document (EPA-450/3-89-019) for estimating fugitive dust emissions from open waste piles and staging areas.

Estimation of emissions based on the methods presented in the above documents can be facilitated by the use of EPA's model CHEMDAT8 and PM-10 Open Fugitive Dust Source

Computer Model both of which are available for downloading from the EPA's Office of Air Quality and Standard (OAQPS) Technology Transfer Network (TTN) Support Center for Regulatory Air Models (SCRAM) Bulletin Board System (BBS).[1]

The *Implementation Guidance* points out that fugitive and operation upsets are not generally expected to increase stack emissions by more than a factor of two over the lifetime of the facility. Therefore, the impact of upset emissions on the long-term risks is likely to be insignificant in comparison to emissions released during normal operating conditions. However, as part of all assessments, the permit applicant will be required to qualitatively evaluate operation upsets. A qualitative assessment will include reviewing and documenting the operating history of the facility. This review should focus on determining the frequency and duration of any process upsets. The need for a quantitative assessment of process upsets will be made on a site-specific basis by the permit writer.

4.2 Constituents of Concern

In the past, regulatory efforts for combustion units have focused primarily on exposure through direct exposure routes, specifically direct inhalation. As a result, the constituents for which indirect exposure are of primary concern need to be identified. These additional compounds can be classified as products of incomplete combustion (PICs)[2] and metals. The following paragraphs provide general guidance on compiling a constituent of concern list for each facility. There are two sets of constituents of concern for an indirect exposure analysis: (1) constituents that are persistent and bioaccumulate in the food chain such as those shown in Table 4.1 and (2) constituents that are soluble and could contaminate surface water drinking sources such as those shown in Table 4.2. In addition, there would be constituents of concern for the direct inhalation pathway, which are not addressed in this document but would include the constituents in both Tables 4.1 and 4.2 that have inhalation health benchmarks. It should be noted the constituents of concern will be the same for all three Tiers. Appendix A presents the physical and chemical properties that can be used in conducting fate and transport modeling for each of the constituents of concern. As part of the modeling, it will be necessary to determine the physical state of the pollutant (i.e., vapor-particle partitioning) at the point of exposure (e.g., the vegetation) and not at the point of release. Appendix A also provides default fv values (i.e., fraction of compound in vapor phase) that should be applied in the absence of site-specific data.

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[1] The Internet address for the TTN 2000 BBS Main Menu is http://134.67.104.12/html/ttnbbs.htm#000 .

[2] U.S. EPA (1994b - *Implementation Guidance*) defines PICs as any organic species emitted from the stack, regardless of the origin of the compound. Therefore, these compounds can include compounds initially present in the feed waste and not completely destroyed in the combustion process and compounds that are formed during the combustion process (e.g., dioxins and furans).

Table 4.1 Potential Constituents of Concern for All Indirect Assessments

Dioxin and Dioxin-like Compounds[a]	Polycyclic Aromatic Hydrocarbons[b]	Polychlorinated Biphenyls[c]	Nitroaromatics	Phthalates	Other Organics	Metals
2,3,7,8-substituted Polychlorinated dibenzo(p)dioxin congeners (2,3,7,8-PCDDs) 2,3,7,8-substituted Polychlorinated dibenzofuran congeners (2,3,7,8-PCDFs)	Benzo(a)pyrene Benzo(a)anthracene Benzo(b)fluoranthene Benzo(k)fluoranthene Chrysene Dibenz(a,h)anthracene Indeno(1,2,3-cd)pyrene	total Polychlorinated biphenyls (all congeners)	1,3-Dinitro benzene 2,4-Dinitro toluene 2,6-Dinitro toluene Nitrobenzene Pentachloronitrobenzene	Bis(2-ethylhexyl) phthalate Di(n)octyl phthalate	Hexachlorobenzene Pentachlorophenol Other unidentified organic compounds (based on TOC emissions)	Antimony Arsenic Barium Beryllium Cadmium Chromium (VI) Lead Mercury (divalent and elemental) Silver Thallium Nickel Selenium Zinc

[a] Under Tier 1, emissions of 2,3,7,8 substituted polychlorinated dibenzo(p)dioxins and dibenzofurans need to be converted to 2,3,7,8-tetrachlorodibenzo(p)dioxin (2,3,7,8-TCDD) toxicity equivalents as specified in the *Screening Guidance*. Toxicity equivalent factors (TEFs) for dioxin/furan congeners are provided in Appendix A. All congeners are then to be modeled using the weighted fate and transport properties of all dioxin/furan congeners with nonzero TEFs. Under Tier 3, all congeners are to be modeled using congener-specific emissions and fate and transport properties. Under Tier 2, the permit applicant may choose to apply either the Tier 1 or Tier 3 modeling approach.

[b] Under Tier 1, emissions of these PAHs are to be converted to benzo(a)pyrene toxicity equivalents (BaP-TEQ). BaP TEFs are provided in Appendix A. All PAHs are then to be modeled using fate and transport properties of benzo(a)pyrene. Under Tier 3, all PAHs are to be modeled using constituent-specific emissions and fate and transport properties. Under Tier 2, the permit applicant may choose to apply either the Tier 1 or Tier 3 modeling approach.

[c] All polychlorinated biphenyl congeners (209 congeners) are treated as a mixture having a single carcinogenic potency, as recommended in the *Screening Guidance.*

Table 4.2. Additional Potential Constituents of Concern for Indirect Exposure Assessments[1]

Constituents	CAS#	Constituents	CAS#
(cis)1,3-dichloropropene	542756	(trans)1,2-dichloroethylene	156605
(trans)1,3-dichloropropene	542756	β-chloronaphthalene	91587
β-hexachlorocyclohexane	319857	1,1-dichloroethylene	75354
1,2-dichlorobenzene	95501	1,2-dichloroethane	107062
1,2-dibromo-3-chloropropane	96128	1,2-dinitrobenzene	528290
1,3-butadiene[a]	106990	1,3-dichlorobenzene[a]	541731
1,4-dichlorobenzene	106467	1,4-dioxane	123911
1,1,1,2-tetrachloroethane	630206	1,1,2-trichloroethane	79005
1,1,2-trichloro-1,2,2-trifluoroethane[b]	76131	1,2,3-trichloropropane	96184
1,2,4-trichlorobenzene	120821	1,1,2,2-tetrachloroethane	79345
1,2,4,5-tetrachlorobenzene	95943	2-chloroacetophenone[a]	532274
2-chlorophenol	95578	2,3,4,6-tetra chlorophenol	58902
2-chloropropane[b]	75296	2,4-D	94757
2,4-dichlorophenol	120832	2,4-dimethylphenol	105679
2,4,5-trichlorophenol	95954	2,4,6-trichlorophenol	88062
3,3'-dimethoxybenzidine	119904	4-nitrophenol[a]	100027
acetaldehyde[a]	75070	a-hexachlorocyclohexane	319846
acetophenone	98862	acrolein	107028
acrylonitrile	107131	anthracene	120127
benzaldehyde[b]	100527	benzene	71432
benzo(e)pyrene[a]	192972	benzo(g,h,i) perylene[a]	191242
benzotrichloride[b]	98077	benzyl chloride	100447
biphenyl[b]	92524	bis(2-chloroethoxy)methane[a]	111911

Table 4.2. Additional Potential Constituents of Concern for Indirect Exposure Assessments[1]

Constituents	CAS#	Constituents	CAS#
bromochloromethane[a]	74975	bromodichloromethane	75274
bromoethene[a]	590602	bromoform	75252
bromomethane	74839	butylbenzyl phthalate	85667
carbon tetrachloride	56235	chlordane	57749
chlorine	7782505	chlorobenzene	108907
chlorobenzilate	510156	chloroform	67663
chloromethane	74873	chromium (total)	7440473
cis 1,4-dichloro-2-butene[a]	764410	crotonaldehyde[b]	123739
DDE	72559	dibutyl phthalate	84742
dichlorodifluoromethane	75718	diethyl phthalate	84662
dimethyl phthalate	131113	ethylbenzene	100414
ethylene dibromide	106934	ethylene oxide	75219
ethylene thiourea[b]	96457	ethylidene chloride	75343
fluoranthene	206440	formaldehyde[b]	50000
heptachlor	76448	hexachlorobutadiene	87683
(lindane)hexachlorocyclohexane[a]	58899	hexachlorocyclopentadiene	77474
hexachloroethane	67721	hexachlorophene	70304
hydrogen chloride[a]	7647010	m-cresol	108394
m-dimethyl benzene (xylene)	108383	maleic hydrazide[b]	123331
methoxychlor	72435	methyl chloroform[a]	71556
methylcyclohexane[a]	108872	methyl ethyl ketone	78933
methylene bromide	74953	methylene chloride	75092
n-hexane	110543	N-nitroso di-n-butylamine	924163
naphthalene	91203	o-cresol	95487
o-dimethyl benzene (xylene)	95476	o-nitroaniline[a]	88744

Table 4.2. Additional Potential Constituents of Concern for Indirect Exposure Assessments[1]

Constituents	CAS#	Constituents	CAS#
o-toluidine	95534	p-chloroaniline	106478
p-cresol	106445	p-dimethyl benzene (xylene)	1330207
p-dinitrobenzene	100254	p-toluidine[b]	106490
pentachlorobenzene	608933	phenol	108952
phosgene[a]	75445	propionaldehyde[a]	123386
propylene dichloride	78875	quinoline	91225
quinone[b]	106514	safrole(5-(2-propenyl)-1,3-benzodioxole)	94597
styrene	100425	tetrachloroethylene	127184
toluene	108883	trans 1,4-dichloro-2-butene	
trichloroethylene	79016	trichlorofluoromethane	75694
vinyl chloride	75014	vinyl acetate	108054
vinylidine chloride	75354		

[1] The information regarding health benchmarks and analytical methods presented in Table 2 is subject to change as new health benchmarks and analytical methods are developed.

[a] Oral health benchmark presently is not available.

[b] No standard analytical method presently available.

Table 4.1 identifies metals and PICs that should always be considered in conducting an indirect exposure assessment. These compounds include the metal and organic compounds identified in the *Screening Guidance* as posing the highest risks to human health via indirect exposures. In addition to these compounds, nickel, selenium, and zinc are identified on Table 4.1. The EPA Office of Solid Waste *Implementation Guidance* also identifies these compounds as constituents of importance for multipathway risk assessments. Furthermore, TOC is identified in Table 4.1 because emission rates based on total organic carbon (TOC) can be used as discussed in Section 4.3 - *Emission Estimates* to account for the unidentified organic emissions or emissions associated with compounds without health benchmarks (see also "Guidance for Total Organics" EPA-600-R-96-036). The permit applicant is required to include all of the Table 4.1 compounds in an assessment unless sufficient information is provided to the permit writer that indicates that a compound could not be emitted by the facility. The compounds identified on Table 4.1 tend to be highly persistent and bioaccumulate in the environment. They are representative of the various classes of chemicals that tend to bioaccumulate and exclusion of these constituents without adequate substantiation that these and similar chemicals could not be emitted from the combustion unit would bias the risk assessment in a non-conservative direction. By focusing the assessment on these compounds, the analysis will evaluate those compounds which typically drive the risks associated with indirect exposures. In addition, the TOC adjustment will allow the emission rates of these compounds to be increased to reflect the presence of those similar compounds (PICs) that may be emitted but have not been adequately characterized as to toxicity. Thus, the constituents included in Table 4.1 are important to include in the analysis for two reasons. First, they are the chemicals that tend to drive the risk in indirect exposure pathways and second, they represent similar constituents that are difficult to identify and quantify and that lack sufficient data for estimating toxicity.

As seen from Table 4.1, the constituents of concern associated with food chain exposures are associated with seven compound classifications including dioxin and dioxin-like compounds; polycyclic aromatic hydrocarbons; polychlorinated biphenyls; nitroaromatics; phthalates; other organics; and metals. Specific issues that relate to a number of these compound classifications and that should be considered by the risk assessor and the permit writer are discussed below.

Dioxin and Dioxin-like Compound - To evaluate carcinogenic risks posed by dioxin and dioxin-like compounds, the U.S. EPA has developed the provisional TEF methodology. This methodology is based on the assumption that the structure-activity relationship of the dibenzo-*p*-dioxins and the dibenzofurans is sufficiently strong that estimates of the long-term toxicity of the minimally tested members of these class of compounds can be reasonably inferred on the basis of available information. Under Tier 1, emissions of 2,3,7,8 substituted polychlorinated dibenzo(p)dioxins and dibenzofurans need to be converted to 2,3,7,8-tetrachlorodibenzo(p)dioxin (2,3,7,8-TCDD) toxicity equivalents (TEQs) using the congener-specific toxicity equivalent factors (TEFs). TEFs for the dioxin/furan congeners are provided in Appendix A, Table A-9. All congeners are then to be modeled using the weighted fate and transport properties of all dioxin/furan congeners with nonzero TEFs. These weighted properties are provided in Appendix A, Table A-3 for 2,3,7,8-TCDD. Under Tier 3, all congeners are to be modeled using congener-specific emissions and the congener-specific fate and transport properties presented in Appendix A, Table A-10. In evaluating cancer risk, congener-specific oral slope factors can be estimated as a percentage of the 2,3,7,8-TCDD slope factor by multiplying each TEF by the 2,3,7,8-TCDD slope factor. Under Tier 2, the permit applicant may choose to model the congeners using the weighted or the congener-specific fate and transport properties.

Polycyclic Aromatic Hydrocarbons (PAH) - In the past, EPA policy has been to use BaP, for which the only verified oral slope factor existed among the carcinogenic PAH, as a toxicological representative of all the carcinogenic PAH and to consider all carcinogenic PAH as equipotent to BaP (U.S. EPA, 1993). However, the inadequacy of this practice became apparent with the availability of empirical data on cancer inducing potencies of the individual PAH. As an alternative, the Agency proposed a provisional PAH TEF approach similar in principle to the 2,3,7,8-TCDD methodology. The PAH TEF approach is to be applied as part of all assessments. Under Tier 1, constituent-specific emissions of PAHs are to be converted to benzo(a)pyrene toxicity equivalents (BaP-TEQ) using the BaP TEFs provided in Appendix A, Table A-8. All PAHs are then to be modeled using the fate and transport properties of benzo(a)pyrene. Under Tier 3, all PAHs are to be modeled using constituent-specific emissions and fate and transport properties. To estimate risks associated with modeled exposure levels, the constituent specific TEFs should be multiplied by the BaP cancer slope factor to obtain modified cancer slope factors. Under Tier 2, the permit applicant may choose to conduct modeling in accordance with the Tier 1 or Tier 3 approach.

Polychlorinated Biphenyls - All polychlorinated biphenyl congeners (209 congeners) are to be treated as a mixture having a single carcinogenic potency, as recommended in the *Screening Guidance*. Therefore, all PCB emissions should be summed and modeled as a single compound (i.e., a mixture) using the physical and chemical properties presented in Appendix A for total PCBs. The health benchmark (i.e, the cancer slope factor) presented for total PCB is based on Arolor 1254, the only PCB for which a verified oral slope factor exists.

Phthalates - Phthalates have been included in Table 4.1 because these compounds tend to bioaccumulate in the food chain and can be of concern to humans exposed through the consumption of animal products (e.g., milk and beef). The phthalates identified for consideration in Table 4.1 include bis(2-ethylhexyl)phthalate and di(n)octyl phthalate. At times, detection of bis(2-ethylhexyl)phthalate at low levels is considered to be a laboratory artifact present in the sample due to contamination which can occur during sampling and analyses. However, unless the permit applicant can demonstrate that this or di(n)octyl phthalate is not being emitted by the facility, both of these compounds should always be included in a facility's risk assessment.

Metals - As discussed in the *Implementation Guidance,* metals speciation information is desirable for risk assessments. However, due to the availability of appropriate analytical methods, speciation data can only be obtained for a limited number of metals (i.e., chromium and mercury). As seen from Table 4.1, of particular interest to food chain exposures is speciation data for chromium and mercury. Chromium can be present in the environment in two oxidation states, trivalent and hexavalent chromium. Hexavalent chromium has been identified as a human carcinogen through direct inhalation. If sufficient data are not available to support the partitioning of chromium between these two valence states and due to the toxicity of hexavalent chromium, chromium emissions should be modeled as hexavalent chromium. If site-specific data are available to support partitioning of chromium between the two oxidation states, this assumption can be modified under any Tier of the analysis. Similarly, mercury can be present in the environment in two oxidation states, divalent and elemental. In the presence of chlorine, mercury emitted by combustion units may be in the divalent state in the form of mercuric chloride ($HgCl_2$). Because mercuric chloride is more soluble than elemental mercury, it will be of greater concern in evaluating indirect risks. Therefore, unless site-specific speciation data on mercury are available, all mercury emissions should be modeled as mercuric chloride, 100 percent in vapor phase. Furthermore, all exposures, excluding fish ingestion exposures, should be evaluated with the health benchmarks provided for mercuric chloride (i.e., inorganic mercury). Because mercury tends to bioaccumulate in aquatic organisms in the organic form, the oral health benchmark (i.e., RfD) for methyl mercury should be applied in evaluating exposures occurring through fish ingestion.

Another metal of concern in the environment is lead. As discussed in Section 6.1.3, health benchmarks (i.e., RfD, RfC or slope factor) are currently not available for lead. In the absence of these health benchmarks, alternate methodologies are recommended for assessing risks posed by lead exposures. Under Tier 1 and 2 assessments, the estimated concentration of lead in soil is to be compared to the soil health-based level given in the *Implementation Guidance* which is a concentration of 400 ppm. Under a Tier 3 assessment, human health risks posed by lead will need to be estimated through the use of the uptake/biokinetic model.

In addition to the compounds identified in Table 4.1, Table 4.2 identifies an expanded list of PIC compounds that are most frequently detected and have been found at the highest concentrations in combustion unit emissions. The list of compounds presented in Table 4.2 was developed based on the Agency's PIC list presented in the *Implementation Guidance* and compounds identified in an article entitled *Incineration of Hazardous*

Waste a Critical Review Update (Dempsey and Opplet, 1993).[3] These compounds should be considered for inclusion in an assessment if it is determined that a facility is located near a surface waterbody that serves as a drinking water source (e.g., within an approximate 20 km radius).

Furthermore, if it is determined that a facility is located near a surface waterbody that serves as a drinking water source, then potential PICs that may result from the incomplete destruction of principle feed constituents will need to be identified and considered in the risk assessment. The following describes two approaches that can be taken in identifying these PICs:

1) For those facilities requesting to use only a limited number of compound-specific (e.g., P- or U- designated wastes) or industry-specific (e.g., K- designated wastes) hazardous waste streams as fuel, the potential principle feed constituents can be identified from 40 CFR Part 261, Appendix VII - *Basis for Listing Hazardous Waste*.

2) For those facilities requesting to thermally treat numerous types of hazardous waste streams as fuel, it is recommended that all of the compounds not previously identified in Tables 4.1 or 4.2 but included on EPA's SW846 Methods 5040 and 8270 be included in the risk assessment.

4.3 Emission Estimates

Emission estimates will need to be developed for every constituent of concern identified as discussed under Section 4.2. In order to maintain the level of conservatism in each tier of an assessment, the emission rates applied under each tier should represent high-end emission rates.[4] In developing constituent-specific emission rates, the Agency (EPA, 1993) provided the following hierarchy for developing stack mass emission rates.

Existing Facilities

For existing facilities (i.e., those built and operational), direct stack measurements should be used. For these facilities, it is preferred that emission rates be developed based on trial burn

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[3] As seen from Table 4.2, analytical methods (i.e., EPA Office of Solid Waste or Office of Air Quality Planning and Standards) are not yet available for measuring a number of the identified compounds. Until appropriate methods are available, it is recommended that emission rates based on TOC be developed for quantifying unidentified organic emissions as discussed in Section 4.3 - Emission Estimates. The exclusion of any additional Table 4.2 compounds from an analysis will be made by the permit writer on a site-specific basis based on the permit applicants demonstration that a compound will not be emitted from a facility.

[4] Throughout an assessment (i.e., Tiers 1, 2, and 3), high-end emission rates should be applied. Specifically, the same rates should be applied under all three tiers.

data. In most cases, the trial burn emission rates will represent rates that are worse than anticipated under normal operating conditions. In the event that routine air monitoring data are available, the permit applicant may want to develop emission rates based on these data to serve as average emission rates. By applying both high-end and average emission rates (i.e., when available) in conducting the analysis, a fuller range of risk can be characterized.

For those compounds on the PIC list (i.e., Tables 4.1 and 4.2) that are sampled for during the trial burn but are below the method detection limit, mass emission rates to be used as input to the risk assessment should be developed based on ½ the quantitation limit, which is usually about three times the detection limit. Both the quantitation and detection limits are calculated values based on the standard deviation (d) of measurements from analysis of replicate (usually at least seven) identically-spiked samples containing the target species at a concentration just above the suspected quantitation limit. The quantitation limit, or lowest reportable concentration, is ten times the standard deviation (10d) and the detection limit is three times the standard deviation (3d) of the measurements. This type of determination typically gives the most accurate value for use in a risk assessment because it takes into account effects of the sampling medium on the measurement as well as differences in analytical systems used for the measurement. Other compounds (i.e., those not on the PIC list) present on the facility's trial burn analyte list that are not detected above the quantitation limit do not need to be considered as part of the analysis (EPA, 1994b).

As discussed above, TOC measurement can be used in developing emission rates to account for the unidentified organic emissions or emissions associated with compounds without health benchmarks which can contribute to the overall risk from the facilities (see also "Guidance for Total Organics" EPA-600-R-96-036). The *Implementation Guidance* points out the risk associated with unidentified organic compounds could potentially be significant.[5] To address the emissions and associated risks attributable to the unaccounted for organic compounds, the EPA' s Office of Solid Waste (EPA, 1994b) recommends the approach outlined below. [6] By applying the following approach the emission rates of the identified organic compounds are increased through the use of an adjustment factor which reflects a ratio of the total mass of organic compounds (TOC) to the mass of identified organic compounds.[7] The methodology used in adjusting emissions is as follows:

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[5] The Agency believes that the risks associated with heavy metals are adequately addressed given the level of compound identification.

[6] For purposes of this Protocol, "unaccounted for compounds" will include those compounds that could not be identified through standard analytical practices and those compounds identified during the trial burn for which health benchmarks are not presently available.

[7] "Identified compounds" will include those compounds that were identified during the trial burn and for which health benchmarks are presently available.

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

where:

$Q_{i,\,adj}$ = Adjusted emission rate of constituent (i)
Q_i = Emission rate of identified constituent (i)
C_i = Stack concentration of the identified compound (i) (carbon basis).
C_{TOC} = Stack concentration of total organic carbon

Under this approach it is assumed that the unaccounted for compounds have similar toxicity and will behave similarly in the environment as the identified organics as a whole. In order not to over adjust the emissions of the compounds included in the assessment, the above equation is applied to the emission rates of the compounds identified during the trial burn rather than being applied exclusively to the emissions rates of the identified constituents of concern (i.e., those compounds identified as specified in Section 4.2). If the above equation was limited to the subset of compounds identified as the constituents of concern, the adjusted emission rates would result in an unrealistic overestimation of risk. Instead, the recommended approach allows the emission rates of the identified constituents of concern for both food chain and surface water exposures to be adjusted upwardly to reflect the fraction of organic emissions that could not be identified and the emissions of the identified compounds for which health benchmarks are not presently available.

Facilities Not Yet Operational

For facilities that have been constructed but are not yet operational or are in planning stages of development, stack test reports for facilities of similar technology, design, operation, capacity and using similar auxiliary fuels, waste feed types, and air pollution control techniques should be reviewed and appropriate emission rates should be developed. If no data relevant to a specific facility exist, then the Office of Air Quality Planning and Standards AP- 42, *Compilation of Air Pollution Emission Factors*, can be used to develop emission estimates.

5.0 EXPOSURE ASSESSMENT

5.1 Human Exposure Scenarios and Routes

This section discusses the exposure scenarios and routes that should be considered under each Tier. Subsections 5.1.1, 5.1.2, and 5.1.3 will focus on Tiers 1, 2, and 3, respectively. It is recommended that the routes of exposure considered under all three tiers include air, soil, food chain, and surface water. As a progression is made from Tier 1 to Tier 3, the exposure scenarios considered in the assessments become less conservative by refining the scenarios through the use of site-specific information. Under both the Tier 1 and 2 analyses, default values are provided for most of the input parameters that define the exposure scenarios. However, under Tier 2 the permit applicant may choose to replace one or several of the default values with parameter values developed based on site-specific information. Under the Tier 3 analysis site-specific information will be required to develop site-specific parameter values.

5.1.1 Tier 1

The Tier 1 assessment focuses on the exposure scenarios and routes identified in the *Screening Guidance*. As discussed in the *Screening Guidance*, the exposure scenarios selected to be included in Tier 1 are considered to be the most significant ones for combustion sources. These scenarios include activity patterns that pose the highest risk (i.e., subsistence farming and fishing) and include exposures such as ingestion of beef, milk, fish, and produce which are believed to result in the most significant indirect exposures (U.S. EPA, 1994b). The Tier 1 scenarios include a subsistence farmer, a subsistence fisher, and an adult and child resident with home gardens (referred to hence forth as home gardeners). It will be assumed that the exposed individuals reside at a worst-case hypothetical point of exposure (i.e., the individuals are assumed to reside at a hypothetical location that represents a point where the maximum air concentration of vapor and combined deposition of particles are assumed to be co-located). The individuals included in each of the four scenarios will be assumed to be exposed to contaminants from the emission sources through the ingestion of aboveground fruits and vegetables, incidental ingestion of soil, direct inhalation of particles and vapors, and the consumption of drinking water if the facility is determined to be located in close proximity to a surface water body that serves as a drinking water source (See Section 4.2). In addition, the subsistence farmer will also consume contaminated beef and milk, while the subsistence fisher will also consume contaminated fish. Table 5.1 provides the Tier 1 default values for consumption rates and the fraction of media contaminated. Figure 5.1 summarizes the exposure scenarios and pathways to be considered under Tier 1. As seen from this table, high levels of exposure are achieved for this Tier by assuming that the fraction contaminated is 1 for subsistence products.

Section 6.1.4 provides guidance for evaluating exposures attributable to the ingestion of dioxin-contaminated breast milk by infants. Based on this guidance, the infant's exposure to 2,3,7,8-TCDD-TEQ through breast milk is estimated based on the mothers estimated exposure for Tier 1 and then is compared to exposures that would result if the mother was exposed at background levels of 2,3,7,8-TCDD. As discussed in Section 6.1.4, research in this area is not yet complete; therefore, the methodology for evaluating these types of exposures are presented in a separate section.

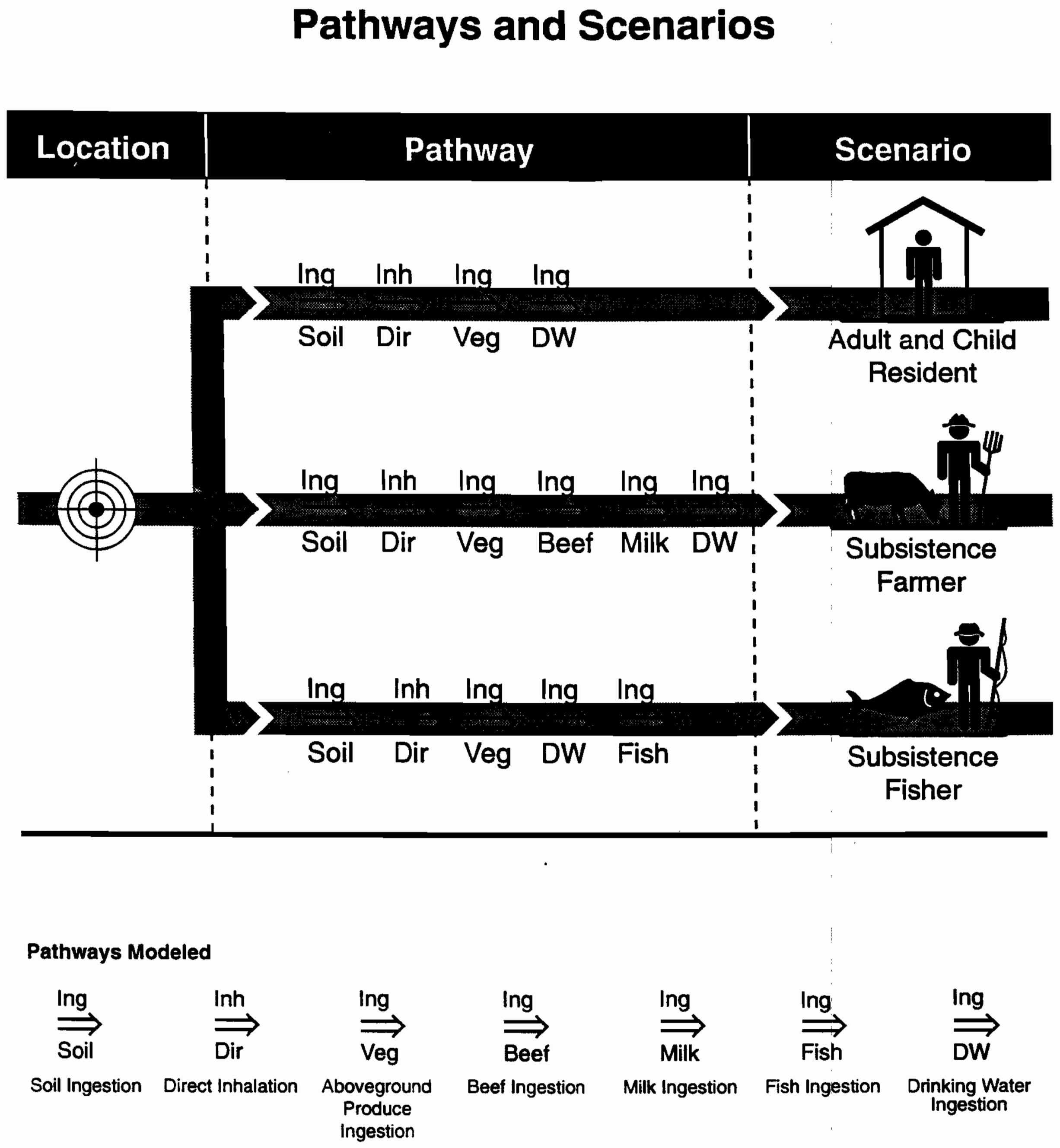

Figure 5.1 Key for Tier 1 and 2 Scenario, Pathway, and Location Icons

Table 5.1. Tier 1 and Tier 2 Consumption Rates and Fraction Contaminated Used in Exposure Scenarios*

Contaminated Food or Media	Exposure Scenario							
	Subsistence Farmer		Subsistence Fisher		Home Gardener		Home Gardener Child	
	Rate	Fraction	Rate	Fraction	Rate	Fraction	Rate	Fraction
Beef (g FW/day)	57	1	NA	NA	NA	NA	NA	NA
Milk (g FW/day)	181	1	NA	NA	NA	NA	NA	NA
Fish (g/day)	NA	NA	60	1	NA	NA	NA	NA
Above-ground fruits and vegetables (g DW/day)	19.7	1	19.7	0.25	19.7	0.25	14	0.25
Soil (mg/day)	100	1	100	1	100	1	200	1
Drinking Water (liters/day)	1.4	1	1.4	1	1.4	1	0.5	1
Air (m^3/day)	20	1	20	1	20	1	12	1
Notes: DW = dry weight, FW = Fresh weight, NA = Not Applicable.								

* Fractions contaminated based on *Screening Guidance* (U.S. EPA, 1994). See Table D.1, page D-2, "Summary of Exposure Inputs" for consumption rate references.

5.1.2 Tier 2

Under Tier 2, site-specific land use information should be used to refine the exposure scenarios modeled under Tier 1. Specifically, land use information is to be used to identify the actual locations of the most impacted residence(s) and the subsistence farm(s). All other input parameters applied under the Tier 1 analysis can be applied under Tier 2 (e.g., consumption rates and fractions contaminated presented on Table 5.1). However, the permit applicant may choose to replace one or several of the default values with parameter values developed based on site-specific information. Table 5.2 summarizes scenarios and pathways that should be considered as part of a Tier 2 analysis. In addition to these scenarios, exposures attributable to the ingestion of dioxin-contaminated breast milk by infants will need to be considered as specified in Section 6.1.4.

Because both vapor air concentration and combined deposition of particles can impact exposure levels, both need to be considered in identifying the location of the receptors (i.e., the location of the most impacted residences and farms). The level of exposure due to air concentrations or deposition is a function of the behavior of the constituent in the environment and the exposure media. For instance, dioxin exposure through the dairy pathway is typically

Table 5.2. Tier 2 Scenarios and Pathways

Scenario	Subsistence Farmer	Home Gardener	Home Gardener Child	Subsistence Fisher
Beef Ingestion	√			
Milk Ingestion	√			
Fish Ingestion				√
Aboveground fruit and vegetable ingestion	√	√	√	√
Soil Ingestion	√	√	√	√
Drinking Water Ingestion	√	√	√	√
Direct Inhalation	√	√	√	√

driven by vapor transfers onto plant leaves, while metal exposure through the soil ingestion pathway is typically driven by deposition of particles. Therefore, to capture the highest levels of exposure, it will be necessary to identify and locate a residence and a farm most impacted by both removal mechanisms. Therefore, in most cases, 2 residential locations and 2 farms will need to be modeled for Tier 2.

To identify the receptors most impacted by these removal mechanisms, isopleth plots of vapor air concentration for an organic compound of concern (e.g., dioxin), and combined deposition of particles for a metal compound of concern (e.g., arsenic) will need to be overlaid with surrounding land use information. The farms and residences most impacted by air concentration and deposition will serve as the receptors of concern for this tier of analysis. As discussed above, modeling will typically need to be conducted for four receptors, 2 farms and 2 residential sites. The subsistence fisher is assumed to reside at the same location as the resident (i.e., home gardener). When identifying the most impacted farms, it should be assumed that any farm has the potential for subsistence activities. For example, if the most impacted farm is currently used only for growing crops, then it should be selected to serve as the location for the subsistence beef and dairy farm because future use of the farm may include subsistence activities. Similarly, it should be assumed that all residential sites have the potential for growing their own vegetables.

5.1.3 Tier 3

The Tier 3 assessment is more detailed than the methodology presented in the *Screening Guidance* and is based primarily on the methodology applied in the *Risk Assessment to the Development of Technical Standards for Emission from Combustion Units Burning Hazardous Wastes* (U.S. EPA, 1996). Under Tier 3, additional exposure pathways and scenarios are added and the Tier 1 and Tier 2 scenarios are refined to allow modeling of activities patterns that are likely to be more representative of land uses around the facility. For example, the subsistence beef and dairy farmer modeled under Tiers 1 and 2 will be replaced by two different subsistence farmers, a subsistence beef farmer and a subsistence dairy farmer. Consequently, all 12 exposure scenarios identified below and depicted in Figures 5.3 through 5.14 will need to be considered in conducting a Tier 3 analysis:[8]

Typical Resident
Child of Typical Resident
Subsistence Dairy Farmer
Subsistence Pork Farmer
Subsistence Fisher
Home Gardener
Typical Farmer
Subsistence Beef Farmer
Child of Subsistence Dairy Farmer
Subsistence Poultry Farmer
Recreational Fisher
Child of Home Gardener

At this point, if a permit applicant has previously conducted a Tier 1 or 2 analysis, the results from these analyses can be closely reviewed and discussed with the permit writer in order to determine which scenarios, pathways, and constituents of concern should be included in a facility's Tier 3 analysis.

The scenarios identified above were selected to represent the general population and special subpopulations. The general population scenarios include the typical resident, typical farmer, and child of the typical resident. The remainder of the scenarios represent special subpopulations whose activities result in increased exposures. The child scenarios identified above were selected to highlight the increased risks due to the child's increased consumption rate of soil, fruits and vegetables, and milk. Dioxin exposures to infants through breast milk will need to be evaluated as specified in Section 6.1.4.

Under Tiers 1 and 2, a number of simplifying assumptions were made concerning exposure pathways and routes which in all likelihood will ensure that the screening exposure levels will exceed the Tier 3 site-specific estimates. For example, it was assumed that the subsistence farmer consumed only beef, milk, and above-ground fruits and vegetables that were homegrown. Under Tier 3, additional pathways of exposure can be considered. These additional pathways include pork, poultry, and egg ingestion.[9] Unlike in the Tier 1 and 2 analyses, it should

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[8] Figure 5.2 provides a key for figures 5.3 through 5.14.

[9] However, the permit writer may need to require that additional pathways be included for a facility based on local land use information. For instance, if local freshwater fish are available in the local market, the fish ingestion pathway could be included under all 12 scenarios.

Scenarios Modeled

Subsistence Beef Farmer

Subsistence Dairy Farmer

Subsistence Pork Farmer

Subsistence Poultry Farmer

Subsistence Fisher

Home Gardener

Typical Resident

Typical Farmer

Recreational Fisher

Child of Subsistence Dairy Farmer

Child of Home Gardener

Child of Typical Resident

Locations for Calculating Level of Contamination

Close to Facility

Average to 20 Kilometers

Each Waterbody

Pathways Modeled

Icon	Pathway
Ing ⇒ Soil	Soil Ingestion
Inh ⇒ Dir	Direct Inhalation
Ing ⇒ Veg	Aboveground Produce Ingestion
Ing ⇒ Beef	Beef Ingestion
Ing ⇒ Milk	Milk Ingestion
Ing ⇒ Pork	Pork Ingestion
Ing ⇒ Egg	Egg Ingestion
Ing ⇒ Chick	Chicken Ingestion
Ing ⇒ Fish	Fish Ingestion
Ing ⇒ DW	Drinking Water Ingestion

Figure 5.2 Key for Tier 3 Scenario, Pathway, and Location Icons

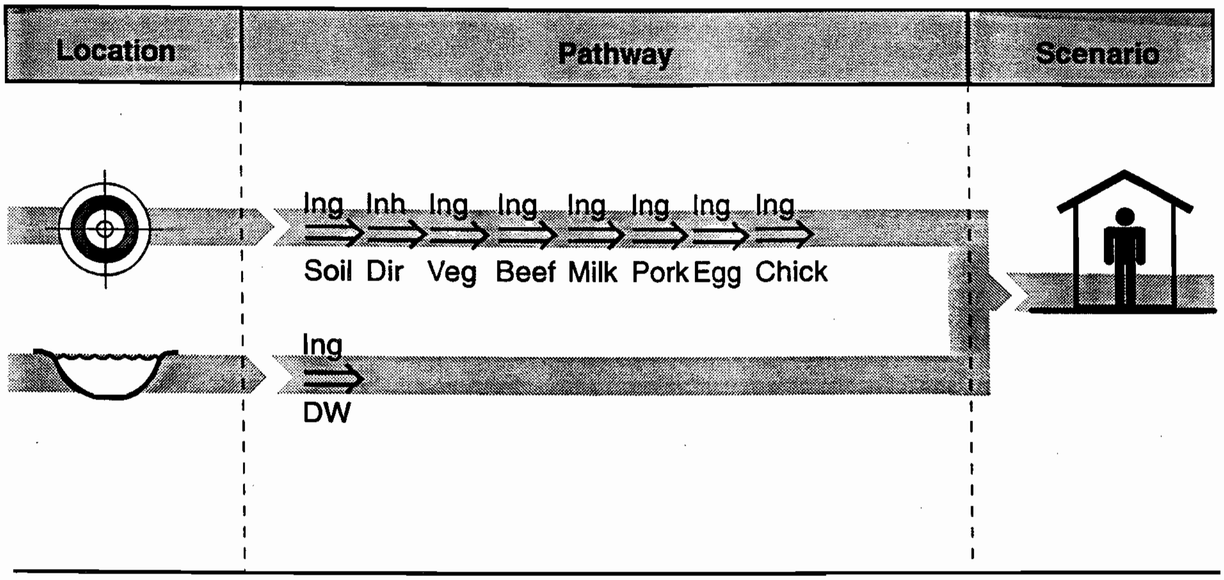

Figure 5.3 Tier 3: Typical Resident Scenario

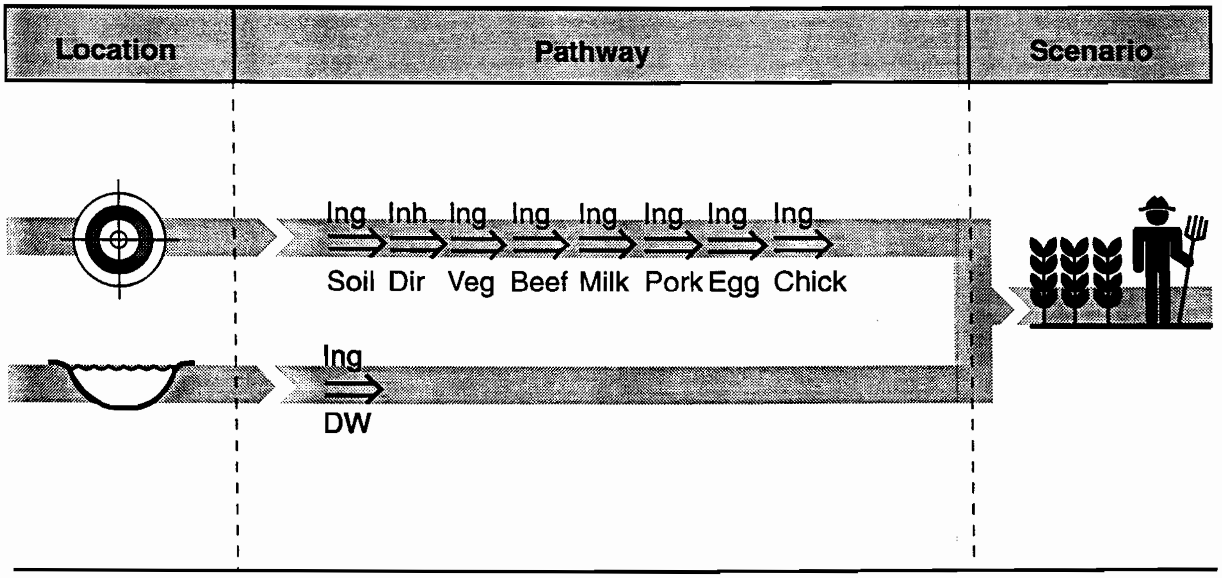

Figure 5.4 Tier 3: Typical Farmer Scenario

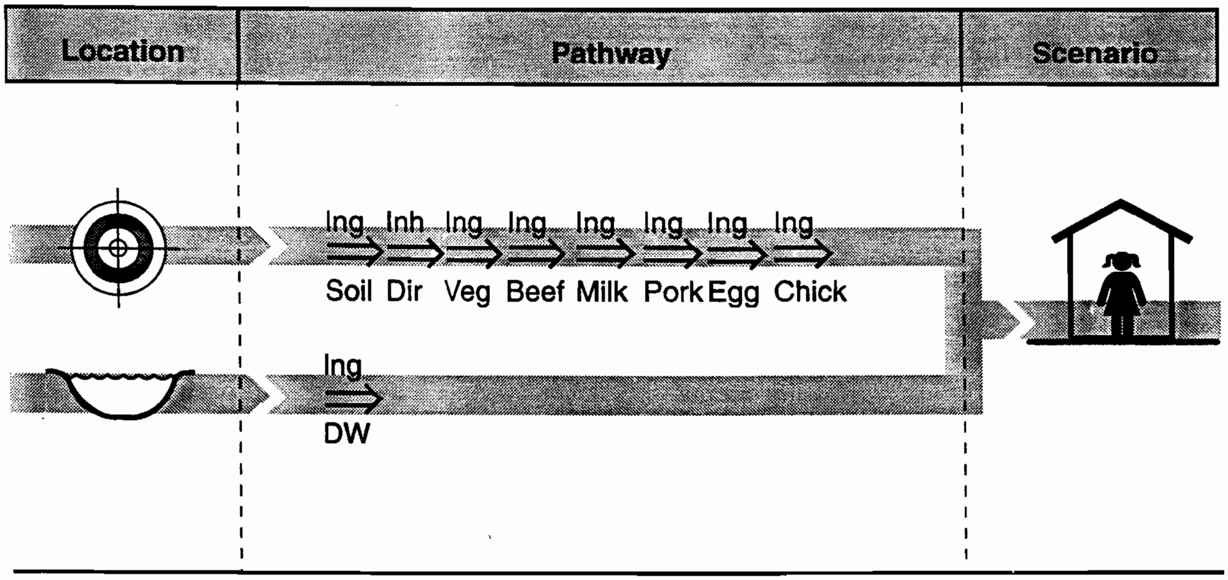

Figure 5.5 Tier 3: Child of Typical Resident Scenario

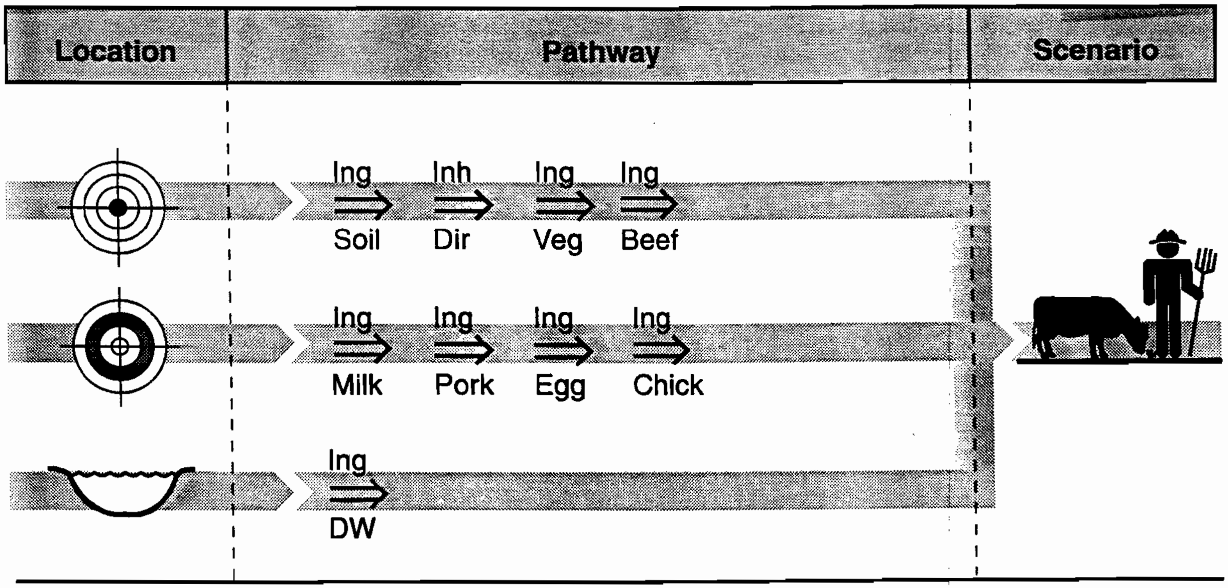

Figure 5.6 Tier 3: Subsistence Beef Farmer Scenario

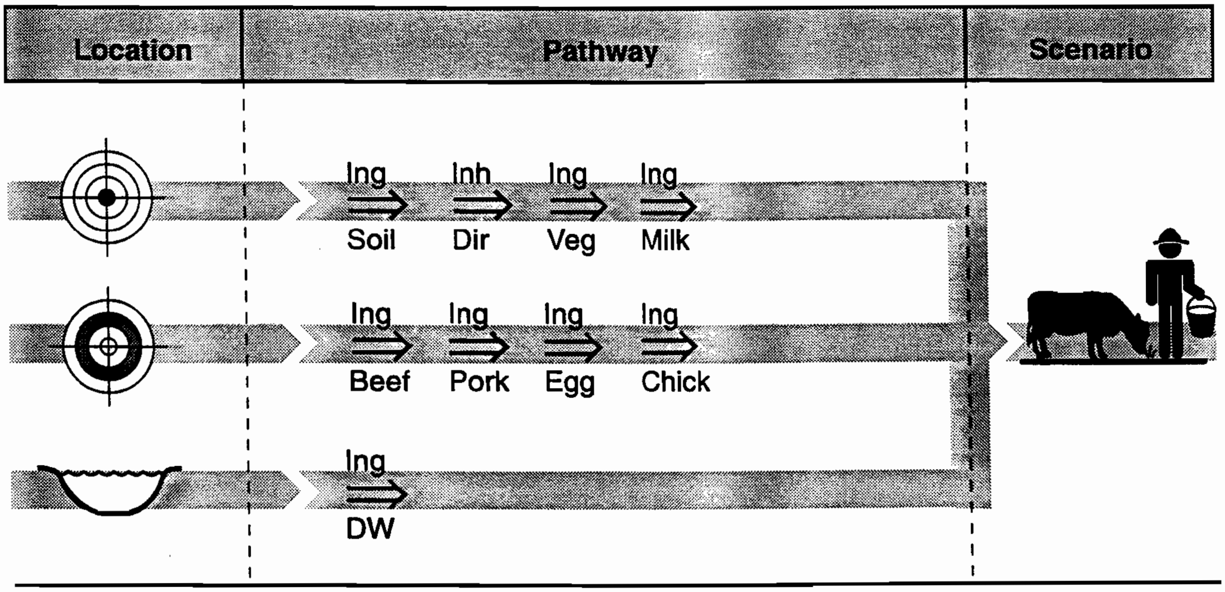

Figure 5.7 Tier 3: Subsistence Dairy Farmer Scenario

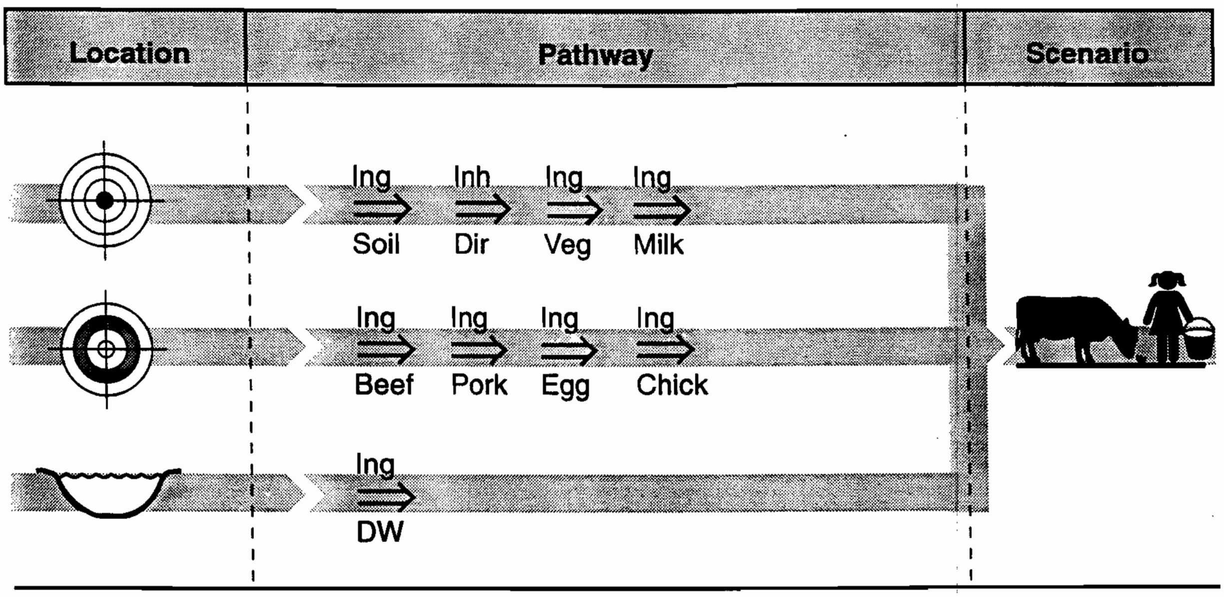

Figure 5.8 Tier 3: Child of Subsistence Dairy Farmer Scenario

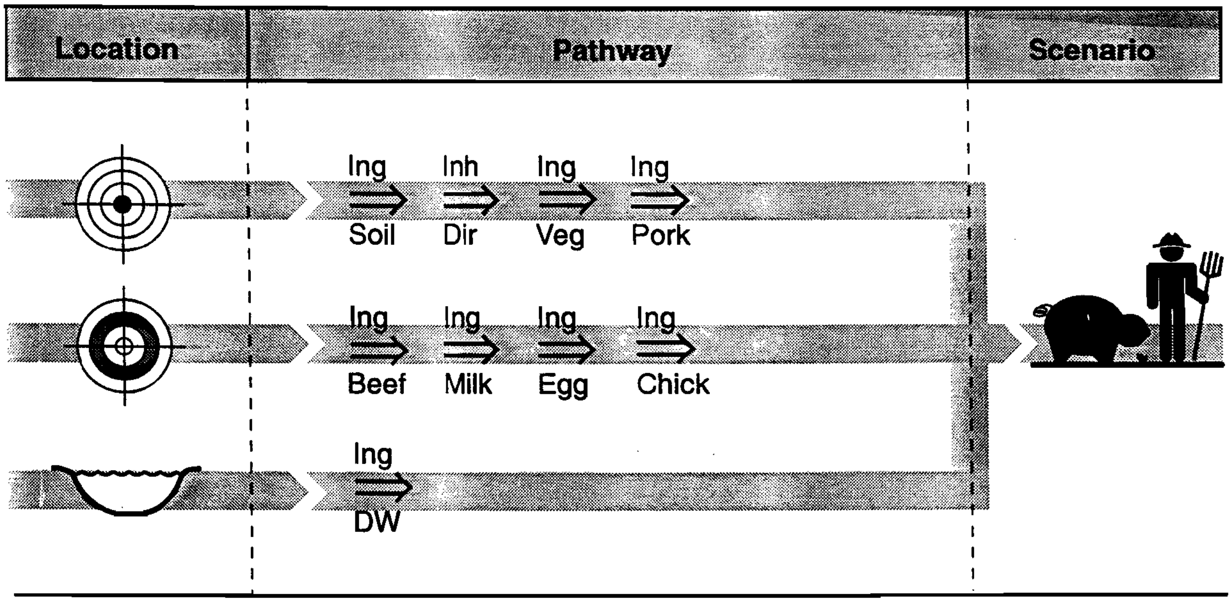

Figure 5.9 Tier 3: Subsistence Pork Farmer Scenario

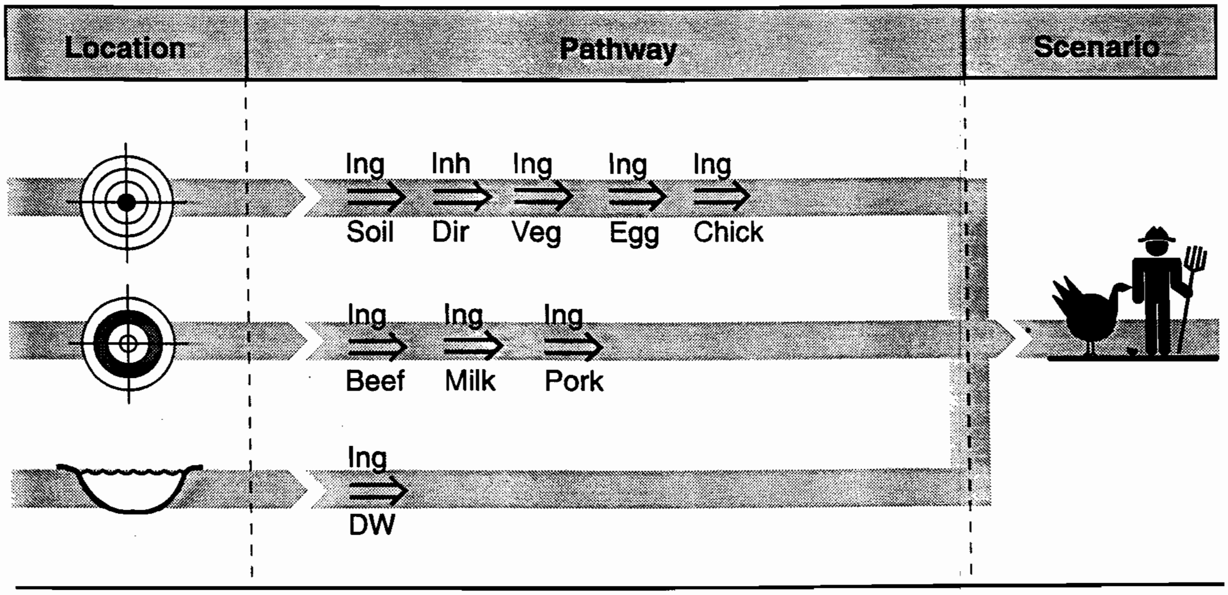

Figure 5.10 Tier 3: Subsistence Poultry Farmer Scenario

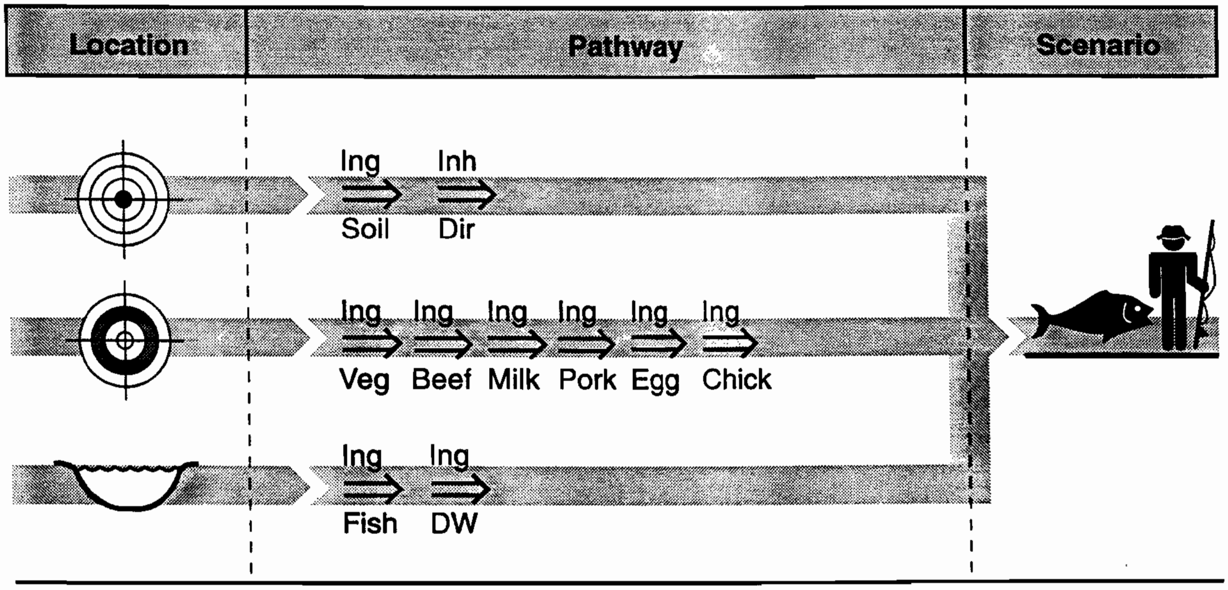

Figure 5.11 Tier 3: Subsistence Fisher Scenario

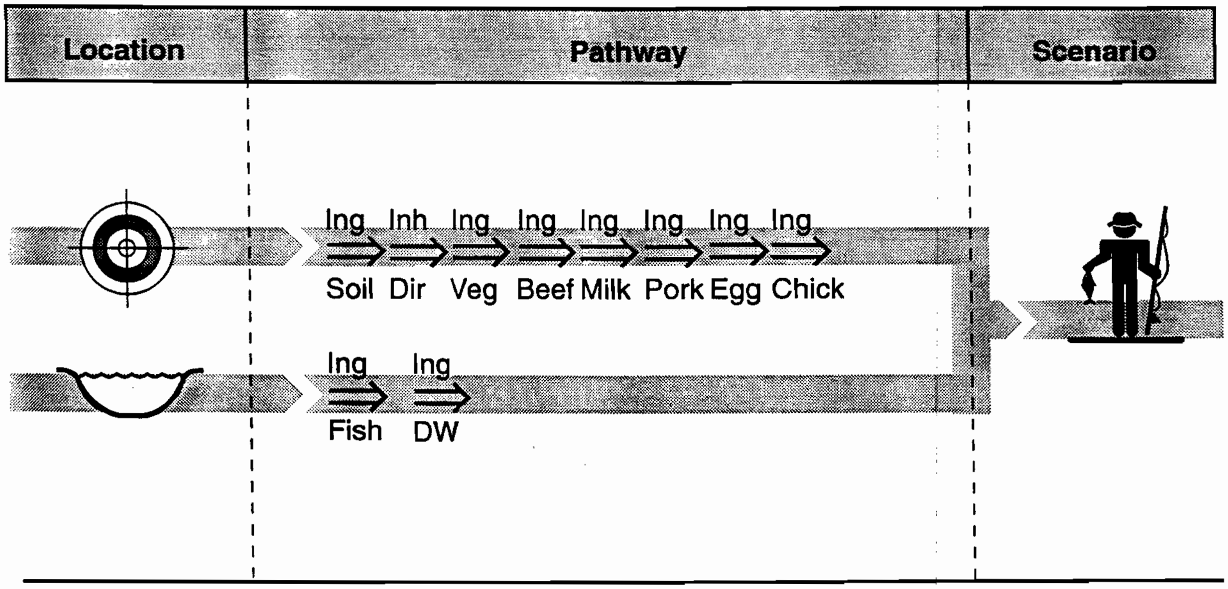

Figure 5.12 Tier 3: Recreational Fisher Scenario

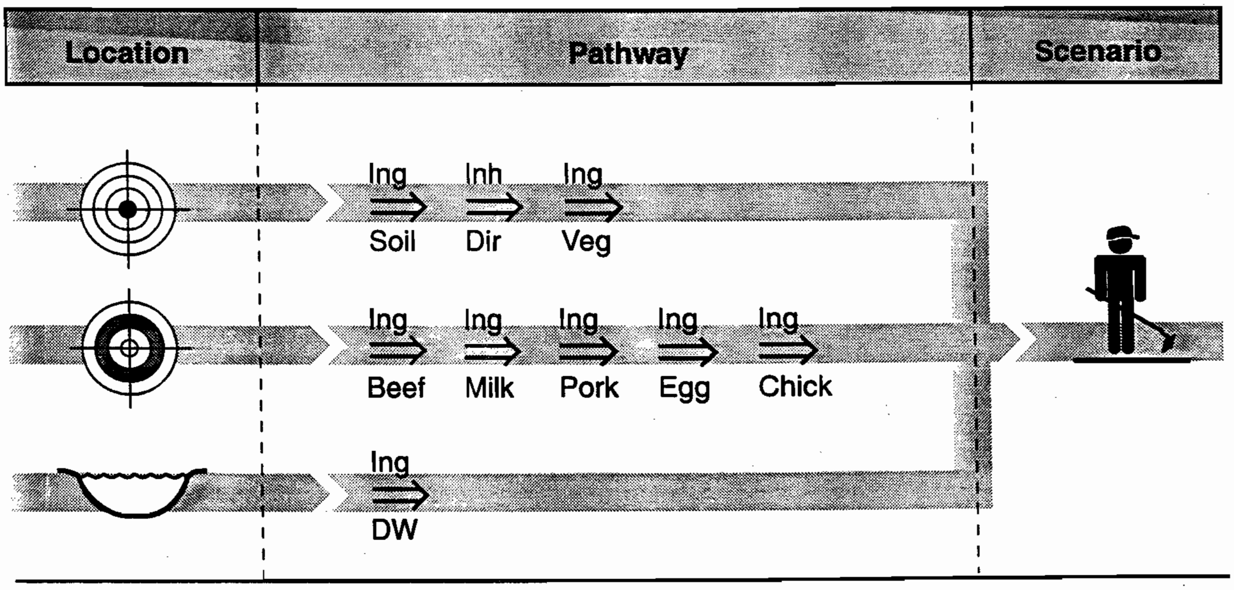

Figure 5.13 Tier 3: Home Gardener Scenario

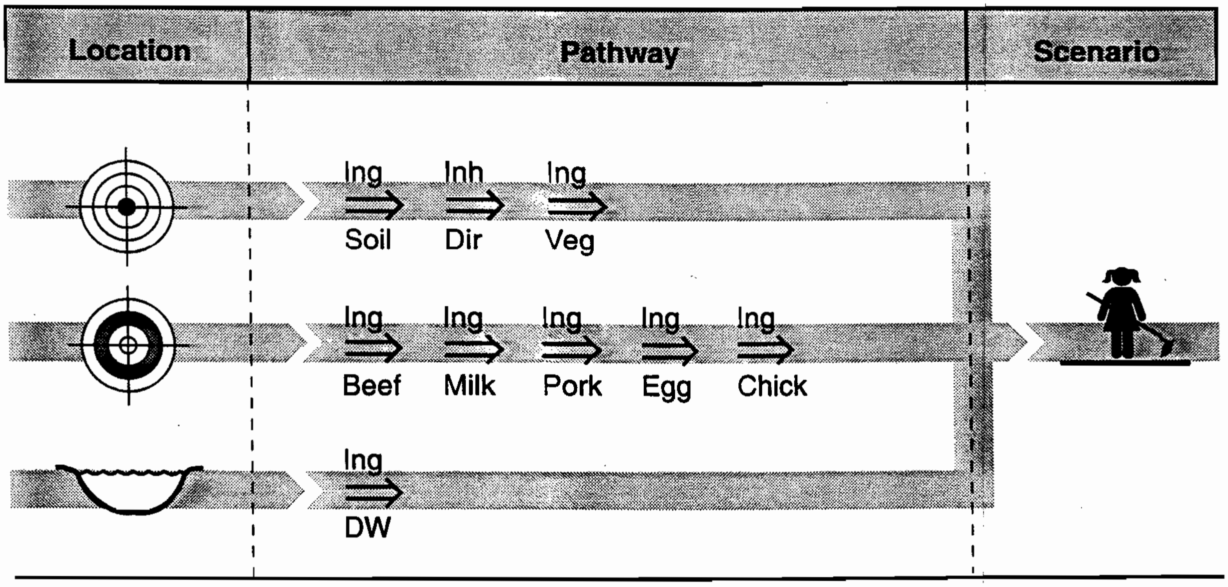

Figure 5.14 Tier 3: Child of Home Gardener Scenario

be assumed that all exposed individuals will consume all types of contaminated media.[10] For example, the subsistence beef farmer will be assumed to eat pork, eggs, and chicken in addition to being exposed through the pathways considered for the subsistence farmer under Tiers 1 and 2. However, it will be assumed that the pork, eggs, and chicken were obtained from the local market and thus only contaminated to a level representative of average contamination across the impacted area. As seen from Figures 5.3 through 5.14, all of the exposed individuals are assumed to be exposed through the consumption or ingestion of food obtained from the local market and contaminated to a level representative of average contamination across the impacted area (i.e., within a 20 kilometer radius of the facility). In order to model exposures resulting from this level of contamination, an average contaminated fraction will need to be estimated. The contaminated fraction is the fraction of the food product that is contaminated by emissions associated with the combustion unit. In any market place, some fraction of food products will be produced locally and represent the contaminated fraction, with the remaining fraction imported from outside of the impacted area. The approach to be applied in developing site-specific contaminated fraction estimates is similar to the methodology applied in the *Risk Assessment Support to the Development of Technical Standards for Emissions from Combustion Units Burning Hazardous Wastes* (U.S. EPA, 1996). Based on this methodology, the fraction contaminated for each food commodity is to be estimated for each county or counties within a 20 kilometer radius of the facility. If multiple counties are to be considered, the lowest fraction contaminated for each food commodity across all counties should be identified and applied in the risk assessment. The fraction contaminated to be applied will be the lesser of two ratios that will need to be calculated: 1) the agricultural production ratio, which is the ratio of the local farm-level production per capita compared to the national farm-level production per capita; and 2) the processing ratio, which is the ratio of the local per capita manufacturing/wholesaling of each commodity compared to the national per capita level. Information on local farm level production per capita can be obtained from the *Census of Agriculture* (U.S. Department of Commerce, 1992a) while manufacturing/wholesaling data can be obtained from data sources such as the *County Business Patterns* (U.S. Department of Commerce, 1992b), the *Census of Manufacturing* (U.S. Department of Commerce, 1987), and the *Census of Wholesale Trade* (U.S. Department of Commerce, 1992c). The lesser of the two calculated ratios should then be applied to the portion of each product ingested that was not assumed to be home-produced. These products include milk, poultry, beef, pork, fruits and vegetables, and eggs. The fraction contaminated applied for any food commodity raised by the subsistence person should always be assumed to be 1. Table 5.3 summarizes the fractions contaminated for each exposure scenario.

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[10] Because Tier 1 and 2 are screening level analyses, exposures were limited to those pathways believed to result in the most significant indirect exposures. Consequently, the estimated exposures are intended to exceed (i.e., be more conservative) the Tier 3 site-specific estimates. By allowing all exposed individuals in Tier 3 to consume a larger variety of contaminated media at a locally determined fraction contaminated (which will likely be less than 1, and may even be zero), the estimated exposures will be more representative of actual site-specific activity patterns.

Table 5.3. Consumption Rates and Fraction Contaminated for Tier 3 Exposure Scenarios

Contaminated Food or Media	Exposure Scenario							
	Subsistence Beef Farmer		Subsistence Dairy Farmer		Subsistence Pork Farmer		Subsistence Poultry Farmer	
	Rate	Fraction	Rate	Fraction	Rate	Fraction	Rate	Fraction
Beef (g FW/day)	57	1	57	local	57	local	57	local
Milk (g FW/day)	181	local	181	1	181	local	181	local
Pork (g FW/day)	17	local	17	local	17	1	17	local
Chicken (g FW/day)	34	local	34	local	34	local	34	1
Eggs (g FW/day)	23	local	23	local	23	local	23	1
Fish (g/day)	1.64	local	1.64	local	1.64	local	1.64	local
Above ground fruits and vegetables (g DW/day)	19.7	1	19.7	1	19.7	1	19.7	1
Soil (mg/day)	100	1	100	1	100	1	100	1
Drinking Water (liters/day)	1.4	1	1.4	1	1.4	1	1.4	1
Air (m^3/day)	20	1	20	1	20	1	20	1
Notes: DW = dry weight, FW = Fresh weight								

Table 5.3. (continued)

Contaminated Food or Media	Exposure Scenario									
	Subsistence Fisher		Recreational Fisher		Typical Farmer		Typical Resident		Home Gardener	
	Rate	Fraction	Rate	Fraction	Rate	Fraction	Rate	Fraction	Rate	Fraction
Beef (g FW/day)	57	local	57	local	57	local	57	local	57	local
Milk (g FW/day)	181	local	181	local	181	local	181	local	181	local
Pork (g FW/day)	17	local	17	local	17	local	17	local	17	local
Chicken (g FW/day)	34	local	34	local	34	local	34	local	34	local
Eggs (g FW/day)	23	local	23	local	23	local	23	local	23	local
Fish (g/day)	60	1	30	1	1.64	local	1.64	local	1.64	local
Above ground fruits and vegetables (g DW/day)	19.7	local	19.7	local	19.7	local	19.7	local	19.7	0.25
Soil (mg/day)	100	1	100	1	100	1	100	1	100	1
Drinking Water (liters/day)	1.4	1	1.4	1	1.4	1	1.4	1	1.4	1
Air (m^3/day)	20	1	20	1	20	1	20	1	20	1
Notes: DW = dry weight, FW = Fresh weight										

Table 5.3. (continued)

Contaminated Food or Media	Exposure Scenario					
	Subsistence Dairy Farmer Child		Home Gardener Child		Typical Resident Child	
	Rate	Fraction	Rate	Fraction	Rate	Fraction
Beef (g FW/day)	32	local	32	local	32	local
Milk (g FW/day)	353	1	353	local	353	local
Pork (g FW/day)	9	local	9	local	9	local
Chicken (g FW/day)	17	local	17	local	17	local
Eggs (g FW/day)	11	local	11	local	11	local
Fish (g/day)	0.35	local	0.35	local	0.35	local
Above ground fruits and vegetables (g DW/day)	14	1	14	0.25	14	local
Soil (mg/day)	200	1	200	1	200	1
Drinking Water (liters/day)	0.5	1	0.5	1	0.5	1
Air (m^3/day)	12	1	12	1	12	1
Notes: DW = dry weight, FW = Fresh weight						

Reference: *Risk Assessment Support to the Development of Technical Standards For Emissions from Combustion Units Burning Hazardous Wastes* (U.S. EPA, 1996).

The consumption rates used in the previous tiers (i.e., Tier 1 and 2) represent average values and can also be applied under this tier of the assessment. However, site-specific consumption rates can also be developed if desired. Table 5.3 identifies the consumption rates that can be applied in conducting this Tier of the analysis.

As in Tier 2, isopleth plots of vapor air concentration and combined deposition of particles for the primary constituents of concern(s) will need to be overlaid with surrounding land use information, to identify the most impacted receptors. If a Tier 1 or 2 analysis was conducted, the primary constituents of concern will be those compounds that drive the risk results from these previous analyses. Based on the overlays, the most impacted actual locations of the following exposed individuals will need to be identified:[11]

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[11] As seen from Figures 5.1 through 5.13, these are the only individuals exposed at subsistence levels (i.e., not just at average levels). Therefore, the actual location of these individuals need to be determined to obtain the air dispersion and deposition outputs for each location.

- *Subsistence Beef Farmer*
- *Subsistence Dairy Farmer and Child*
- *Subsistence Poultry Farmer*
- *Subsistence Fisher (assumed to reside at home gardener location)*
- *Subsistence Pork Farmer*
- *Home Gardener and Child* [12]

In the event that an individual participating in any of the subsistence farming activities identified above can not be located, the permit applicant should discuss with the permit writer the feasibility of such activities occurring in the area. At this point, a determination will be made as to whether the most impacted farm has the potential for that type of activity and should be modeled as such. The remainder of the exposed individuals will need to be modeled using the average fractions of contamination discussed above and air concentrations and deposition rates averaged over an area 20 km out from the facility.

5.2 Fate and Transport Modeling

This section provides guidance in conducting fate and transport modeling of chemical compounds emitted from the facility of concern. Once pollutants are released from emission sources, contaminants may reach media or food through many pathways. In estimating contamination to soil, plants, drinking water, and animal tissues, it is recommended that only those pathways that are typically associated with significant contributions to the media and food concentrations be considered. For example, soil will be assumed to be contaminated by wet and dry deposition of particle and vapors. Above-ground vegetation, for human and animal consumption, will be assumed to become contaminated through the deposition of particles onto plants, transfer of vapor phase contaminants onto plants, and uptake through roots. Animal products (e.g., milk and beef) contamination will occur through the animals ingestion of contaminated pasture grasses, feed, and soil. Contamination of the water body occurs from erosion of contaminated soil from the watershed, deposition to the water body, and diffusion to the water body. Fish are contaminated through bioaccumulation (or bioconcentration for some compounds) from the water column, dissolved water concentration, or bed sediment depending on the type of chemical.

The fate and transport equations that need to be applied in conducting any Tier analysis are presented in Appendix B. When applicable, default parameters are also provided in Appendix B. Appendix D identifies the data sources that were used in developing the default parameter values. Constituent-specific physical and chemical properties required as input to the fate and transport modeling effort will be provided in Appendix A.

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[12] In most cases, the location of this receptor should be the same as the location that would have been considered under Tier 2.

5.2.1 Air Dispersion and Deposition Modeling

The results of the air dispersion and deposition modeling represent the initial fate and transport of constituents in the environment. Air concentrations of vapor and particles, wet and dry deposition of particles, and wet deposition of vapors are modeled for all three tiers. An updated version of the ISCSTDFT model recommended in the *Screening Guidance* - Industrial Source Complex Short Term Model (ISCST3) - is used to estimate the air concentrations and deposition rates needed for the indirect exposure assessment. It is Gaussian plume model that is applicable in simple, intermediate, and complex terrains, and it can simulate both wet and dry deposition and plume depletion.

5.2.1.1 Determination of Environmental Setting Required for Air Modeling

Before beginning the air dispersion modeling, the area around a facility should be investigated to determine the complexity of the terrain, to identify the types of land uses in the area, and to select water bodies for modeling exposures to contaminants through drinking water and fish ingestion. Characterizing these environmental settings is crucial in the risk assessment process.

The terrain type surrounding a facility can have a large impact on the air dispersion and deposition modeling results and ultimately on the risk estimates. The determination of whether the facility is in an area of intermediate or complex terrain is made following the guidance provided in the *Guideline on Air Quality Models* (U.S. EPA, 1993b). The air modeling requires actual terrain elevations in areas of complex terrain. Actual terrain features may also have significant effects in areas of intermediate terrain.

Another environmental setting characterization that is important for the air dispersion portion of the fate and transport modeling is the roughness height. The roughness height is a measure of the variation in height of individual elements on the landscape such as trees and buildings. A representative average roughness height is developed from the land use identified within approximately 5 kilometers of the stack. Roughness height values for various land use types are presented in Appendix B of the PCRAMMET User's Guide for the ISCST3 Model (U.S. EPA, 1995b).

Two or more water bodies are generally modeled for estimating the risks from fish ingestion and ingestion of drinking water. Discussions with local authorities and the use of topographic maps are used to identify the water bodies that are most impacted by emissions from the facility. Water bodies closest to the facility will typically have higher deposition rates. However, in order to estimate risks through the fish ingestion pathway, the water body must be large enough to sustain a fish population. Generally, risks will be estimated for a water body even if a fish advisory is posted. Any surface water body that is used for a drinking water source should be modeled if it is within 20 kilometers of the stack. The area of the watershed associated with the identified water body is also important due to the runoff of soils to the water body.

Thus, a small close stream may not necessarily pose the highest risks. Effective watersheds are used if the watershed is much larger than the area of interest near the facility, with the watershed area of interest limited to approximately 50 kilometers (i.e., which is the limit of the ISCST3 model) of the facility. Once the water bodies of interest are identified, the area of each water body and watershed are mapped using U.S.G.S. topographic maps.

Additional surface water parameters to be determined are listed in Table 5.4. The fraction of the watershed which is impervious is a function of the urbanization of the area around the facility. The size of the watershed is multiplied by the fraction impervious to arrive at the impervious area of the watershed. Water body current velocities and volumetric flow rates can be obtained from EPA's REACH Data files for larger rivers (U.S. EPA, 1995c). State or local Geologic Surveys may also keep records on water bodies. Volumetric flow rates for smaller streams or lakes can be calculated as the product of the watershed area and one-half of the local average annual surface runoff, which may be obtained from the Water Atlas (Gerghaty, et al., 1973). Current velocities can be calculated as the volumetric flow rate divided by the cross-sectional area (current velocities are not used in the equations for lakes). Water body depth can be obtained from state or local sources.

Table 5.4 Water Body Parameters Required for Fate and Transport Modeling

Parameter	Units
Water body surface area	square meters
Watershed surface area	square meters
Impervious watershed area	square meters
Average Volumetric Flow Rate	cubic meters per year
Current Velocity	meters per second
Depth of Water Column	meters
Universal Soil Loss Equation (USLE) rainfall/erosivity factor	unitless

5.2.1.2 Preparing Meteorological Data

In order to model wet and dry deposition, the ISCST3 model requires a variety of meteorological data, which are available from several different sources. The *Guideline on Air Quality Models* (U.S. 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 as are available should be used with a minimum of one year being required. When available, onsite data are preferred for air dispersion and deposition modeling. Nearby airport data can be used in some instances, if onsite data are unavailable. However, for the level of detail required in the Tier 3 analysis, it is recommended that site-specific surface meteorological data be used. In the cases where onsite data are unavailable, some meteorological files necessary for running ISCST3 are also available on the EPA's Support Center for Regulatory Air Models bulletin board system (SCRAM BBS) for National Weather Service (NWS) stations located in North Carolina.[13] However, these files do not contain all of the elements necessary for modeling wet and dry deposition. Specifically, these abbreviated surface observations do not contain surface station pressure values, types of precipitation (present weather), nor precipitation amounts. These additional data elements are available for most airport stations from the Solar and Meteorological Surface Observation Network (SAMSON) CD-ROM (NOAA, U.S. Department of Commerce, 1993). While the ISCST3 model is not very sensitive to the surface pressure variations and default values may be used, precipitation types and amounts are necessary for modeling wet deposition.

Additional data required for ISCST3 modeling are upper air data. The upper air files for Greensboro are available through the year 1992 on the SCRAM BBS. These files are the most appropriate for use throughout the central portion of the state. However, they should be used with caution when developing upper air data for the mountains and the coast. The additional surface observation elements needed and more current upper air observations may be purchased from the National Climatic Data Center (NCDC) in Asheville.[14]

The PCRAMMET User's Guide for ISC3 contains detailed information for preparing the required meteorological input file for the ISCST3 model. PCRAMMET can be used with either SAMSON format data or NWS format data. For onsite data, a new version of Meteorological Processor for Regulatory Models (MPRM) is used to mesh onsite data with NWS data for preparing the meteorological input file. Both programs and their User's Guides are available for downloading from the SCRAM BBS.

5.2.1.3 Preparing ISCST3 Input Files

A thorough discussion of how to prepare the input files for ISCST3 can be found in the ISC3 User's Guide (U.S. EPA, 1995a). The model and the User's Guide are available for downloading from the SCRAM BBS. ISCST3 requires site-specific inputs for source parameters, receptor locations, meteorological data, and terrain features. The model is setup through the use of a control file. The control file is divided into the sections listed below that are identified in the control file by two-letter keywords.

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[13] The SCRAM BBS is a part of the Office of Air Quality Planning and Standards Technology Transfer Network (OAQPS TTN) which can be accessed through Internet (http://134.67.104.12/html/ttnbbs.htm#000).

[14] National Climatic Data Center, Federal Building, 37 Battery Park Avenue, Asheville, NC 28801-2733. Customer Service: (704) 271-4871.

Section	Keyword
Control	CO
Source	SO
Receptor	RE
Meteorology	ME
Terrain	TG
Output	OU

Specific directions for running the ISCST3 model are provided in the ISC3 User's Guide.

The ISCST3 air model is run using a unit emission rate of 1 gram per second. Adjustments for facility-specific emission rates occur later in the indirect modeling process. However, the model does require facility-specific information on the incinerator stack in order to estimate air concentrations and deposition rates. The facility-specific inputs that are applied in the air dispersion model include the following:

- *Stack height (meters)*
- *Stack inside diameter (meters)*
- *Exit velocity (meters/second)*
- *Stack gas temperature (degrees kelvin)*
- *Building heights and widths (meters) and locations in relation to the stack*
- *Particle size distributions.*

Building wake effects can influence plume dispersion, and, therefore, building downwash should be considered in some instances. Building dimensions and locations are used together with the stack parameters in the Building Profile Input Program (BPIP) to investigate the potential effect of building downwash. The BPIP program can also be downloaded from the SCRAM BBS. The output file is in a format that can be copied and pasted directly into the ISCST3 control file.

As noted previously, the particle size distribution is required to model the air concentration and deposition rates of particles. If site-specific data on the particle size distribution is available, then it should be used. In the absence of such information, Table 5.5 contains default particle size distributions which are typical of combustor emissions. The distributions listed in the table are presented in terms of surface area and mass, and the choice of which distribution to use depends on the constituent of concern. Organic compounds are assumed to condense and sorb on the outer surface of the particulate matter. Therefore, organics should be modeled using the area size distribution. Metals are assumed to be homogeneously dispersed throughout the entire particle, so that mass distribution should be used. The distribution presented in Table 5.5 is based on the distribution applied in the *Risk Assessment Support to the Development of Technical Standards for Emissions from Combustion Units Burning Hazardous Wastes* (U.S. EPA 1996). If site-specific data are to be used in developing particle size distributions, guidance is provided in the *Addendum* (U.S. EPA, 1993a) for making conversions from mass based distributions to a surface area based distributions.

Table 5.5 also lists the scavenging coefficients for wet deposition of particles (Jindal and Heinhold, 1991). The frozen precipitation scavenging coefficients are assumed equal to the liquid precipitation scavenging coefficient (PEI, 1986), as a conservative estimate. Also, presented in the table are coefficients for the scavenging of vapor. Although wet scavenging of vapors depends on the properties of the chemicals involved, not enough data are available to develop chemical-specific scavenging coefficients adequately at this time. Therefore, vapors are assumed to be scavenged at the rate of the smallest particles whose behavior in the atmosphere is assumed to be more influenced by the molecular processes that affect vapors than the physical processes that often dominate behavior of larger particles. The value for vapor scavenging was obtained from Jindal and Heinhold (1991).

Table 5.5 Particle and Scavenging Coefficient Input Parameters

Variable	Screening Value	Units
Particle density	1.0	g/cm³
Particle Sizes	1.0, 6.0, 15.0	size range median, µm
Fraction of emissions in each particle size by surface area (Modeling of organics)	0.78, 0.19, 0.03	unitless
Fraction of emissions in each particle size by mass (Modeling of metals)	0.33, 0.48, 0.19	unitless
Particle scavenging coefficients for liquid and frozen precipitation	4.0E-5, 4.2E-4, 6.7E-4	hr/mm-s
Vapor scavenging coefficient (based on a 0.1 µm particle)	1.7E-4	hr/mm-s

If the investigation of the environmental setting around the site indicates that terrain may influence plume dispersion, the terrain pathway should be used in the ISCST3 modeling. Site-specific terrain inputs consist of elevations at specific receptor locations and a gridded terrain file created using geographic information system (GIS) programs. The gridded terrain file should contain elevations at every 100 meters over the area modeled.

Two sets of air modeling runs are required for all tiers. The first set is run initially using a polar grid of receptors, at 22.5° intervals, at distances of 100, 150 200, 300, 400, 500, 700, 1000, 1500, 2000, 3000, 4000, 5000, 7000, and 10,000 meters from the source centered at the origin. To estimate the screening level Tier 1 risk estimates, maximum values for the air concentration of vapors and the combined deposition of particles are to be assumed to be colocated and are to be used. For the Tier 2 and 3 risk estimates, actual exposure locations are to be used. The air modeling output values from the polar receptor closest to the exposure location are to be used. Dry deposition of vapors will be treated through the use of a deposition velocity of 3 cm/s applied to the air concentration of vapors.

A second set of receptors is used for air modeling outputs to assess the indirect risk for the surface water pathways. The water bodies and their associated watershed should be modeled with a receptor grid covering the area of the watershed only, out to a distance of 20,000 meters from the incinerator. Receptors should be placed on a Cartesian grid at 500 meter intervals over the entire watershed area. Air concentration of vapors, wet deposition of vapors, and combined deposition of particles areally averaged over the watersheds and water bodies are used in the calculation of indirect exposures through the surface water pathways.

The ISCST3 model can produce a plotter output file which facilitates averaging over the watershed and water body areas. The plotter file lists the X and Y coordinates and the deposition rates or air concentration values in a format that can easily be pulled into a spreadsheet program and parsed. The values are averaged to arrive at the areally averaged air concentrations and deposition over the watershed and water body.

5.2.1.4 Estimating Chemical-Specific Air Concentrations and Deposition Rates

The ISCST3 results are modeled using a unit emission rate of 1 gram/second from the combustor. However, the air modeling results have to be converted to chemical-specific air concentrations and deposition rates for the exposure analysis. This conversion accounts for chemical-specific emission rates (Q) and the partitioning of chemicals between the vapor and particle phases. The relationship between the emissions and air concentrations and deposition rates are linear and can be expressed by the following example:

$$\frac{\textit{Chemical Specifc Air Concentration}}{\textit{Chemical Specific Emission Rate}} = \frac{\textit{Air Modeling Output Air Concentration}}{\textit{Unit Emission Rate}}$$

The chemical-specific air concentrations and deposition rates can be obtained as follows:

$$\textit{Vapor phase air conc.} = \frac{\textit{Air Modeling Output Vapor Conc. x Chemical Specific Emission x fv}}{\textit{Unit Emission Rate}}$$

$$\textit{Particle phase air conc.} = \frac{\textit{Air Modeling Output Particle Conc. x Chemical Specific Emission x } (1 - fv)}{\textit{Unit Emission Rate}}$$

Additionally, the partitioning of a chemical into the vapor and particle phase must be taken into account when calculating the chemical-specific air concentrations and deposition rates. The partitioning of the emissions between particle and vapor phase is crucial in the risk assessment process. The partitioning used in modeling should reflect partitioning at the point of exposure (i.e., not at the point of release) and thus is a function of environmental conditions rather than flue gas conditions. Partitioning is dependent on the physical/chemical properties of constituents such as vapor pressure, molecular weight, and Henry's Law constants, and is, therefore, chemical-specific. Appendix A provides default fraction of vapor values (i.e., fv values) that can be applied in conducting an assessment. For metals other than mercury, the fraction in vapor phase is assumed to be zero (i.e., the compounds are assumed to be entirely present in particle phase). As discussed previously, all mercury emissions should be modeled as mercuric chloride in the absence of site-specific speciation data. Furthermore, the partitioning of mercuric chloride should be modeled as 100 percent in vapor phase. For organics other than dioxins, the fraction of vapor values presented in Appendix A were calculated from the Junge equation cited in Bidleman (1988) and can range from entirely vapor phase to entirely particle phase depending on the chemical. The fraction of vapor phase presented in Appendix A for each individual dioxin congener were obtained from the *Risk Assessment Support to the Development of Technical Standards for Emissions from Combustion Units Burning Hazardous Wastes* (U.S. EPA, 1996). The fraction of vapor presented for 2,3,7,8-TCDD TEQ in Appendix A is intended to represent the dioxin TEQs by weighting data for each dioxin and furan congener using TEF's (U.S. EPA, 1994). For each compound of concern, vapor phase air model outputs are multiplied by the fraction of emissions in the vapor phase under ambient conditions (fv) and the emission rate, Q. Similarly, all particle-bound air model outputs are multiplied by the fraction of emissions in the particle phase (1-fv) and the emission rate, Q.

5.2.2 Estimation of Media Concentrations

This section discusses the methodology used to calculate contaminant concentration in the various media. In estimating contamination to soil, plants, and animal tissues, only those pathways that are typically associated with significant contributions to contaminant concentrations in the media or food have been considered. Other pathways have been omitted or their contributions were assumed to be negligible in comparison with the pathways being evaluated. For example, contamination of surface water bodies through ground water was considered negligible and thus omitted. The chemical-specific air concentrations and deposition rates calculated from the air dispersion and deposition modeling are the inputs to the media equations. Together with the consumption rates by animals, and the meteorological, water body specific, and default soil parameters presented above and in Appendix B, the final concentrations in the media are calculated.

5.2.2.1 Air Concentrations for Direct Inhalation

Air concentrations of contaminants used in calculating direct inhalation risks will be characterized as the summation of vapor air concentration and particle-bound air concentration of contaminants. As discussed previously, direct inhalation exposure is evaluated at different locations depending on the tier. Equations for calculation of air concentrations of contaminants are contained in Appendix B.5.

5.2.2.2 Concentrations in Soil

Calculation of contaminant concentration in the soil is applicable to all three tiers. The soil concentrations of contaminants will be characterized as the summation of the particle-bound and vapor phase deposition of contaminants to the soil. Both wet and dry deposition of particles and vapors will be considered, with dry deposition of vapors calculated from the vapor air concentration and the dry deposition velocity. The calculation of soil concentration incorporates a term that accounts for loss of contaminant by several mechanisms, including leaching, erosion, runoff, degradation, and volatilization. These loss mechanisms all lower the soil concentration associated with the deposition rate. Equations for soil concentration and soil losses are contained in Appendix B.1.

The soil concentrations may take a number of years to reach steady state. As a result, the soil equations to calculate the average soil concentration over the time period of deposition were derived by integrating the instantaneous soil concentration equation over the time period of deposition. For carcinogens, two forms of the soil-averaging equation are used: one form for when the exposure duration is greater than or equal to the facility operating lifetime, and a second form for when the exposure duration is less than the operating lifetime. For noncarcinogens, the highest 1-year annual average soil concentration should be used.

5.2.2.3 Concentrations in Aboveground Produce

Calculation of contaminant concentration in aboveground produce (fruits and vegetables) is applicable to all three tiers. The indirect exposure due to the ingestion of aboveground produce depends on the total concentration of contaminants of concern in the leafy and fruit portions of the plant. The three mechanisms by which produce can be contaminated include the following:

- *Root uptake - the root uptake of contaminants available from the soil and their transfer to the aboveground portions of the plant*
- *Deposition of particles - wet and dry deposition of particle-bound contaminants on the leaves and fruits of plants*
- *Vapor transfer - the vapor phase uptake of the plants through their foliage.*

The total contaminant concentration in aboveground produce is calculated as a sum of contamination occurring through all three of these mechanisms. Equations for calculation of contaminant concentration in aboveground produce are contained in Appendix B.2.

The methodology used to estimate contamination through vapor transfer considers the reduction of lipophilic contaminant concentrations resulting from mechanisms responsible for inhibiting the transfer of the contaminant (i.e., the shape of the produce) and the removal of the contaminants from the edible portion of the produce (e.g., washing, peeling, and cooking). Specifically, the algorithm used to estimate contamination through vapor transfer was developed to estimate the transfer of contaminants into leafy vegetation rather than into bulky aboveground vegetation, such as apples. Because of the shape of bulky produce, transfer of contaminant to the center of the produce is unlikely to occur and, as a result, the inner portions will be largely unimpacted. Additionally, typical removal mechanisms, such as washing, peeling, and cooking, will further reduce residues. Therefore, applying this algorithm to bulk produce would result in overestimating contaminant concentrations. An adjustment factor (VG_{ag}) has been incorporated into the algorithm to address this overestimation for lipophilic compounds (i.e., compounds with a log K_{ow} value greater than 4). In this Protocol, Vg_{ag} is assigned a value of 0.01 for lipophilic compounds for all aboveground vegetation intended for human consumption. The compound-specific transfer factors for soil and vapor to aboveground produce are provided in Appendix A.

5.2.2.4 Concentration in Beef and Dairy

Calculation of contaminant concentration in beef and dairy products is applicable to all three tiers. The contaminant concentrations in beef tissue and milk products are estimated based on the amount of contaminant that the cattle are assumed to consume through their diet. Uptake of chemicals via inhalation and ingestion of contaminated water is assumed to be insignificant. The cattle's diet is assumed to consist of forage (i.e., pasture grass and hay), silage, and grain. Additional contamination of the cattle occurs through the ingestion of soil. The amount of grain, silage, forage, and soil consumed is assumed to vary between dairy and beef cattle; Table 5.6 lists the consumption rates for cattle. In conducting analyses, it should be assumed that each item consumed by the animal originated from the impacted farm, therefore the fraction contaminated is assumed to be 1. Equations for calculating contaminant concentration in beef and milk are contained in Appendix B.3.

Table 5.6 Default Consumption Rates for Beef and Dairy Cattle

Parameter	Beef Cattle	Dairy Cows	References
Consumption rate			
forage	8.8 kg/d (dw)	13.2 kg/d (dw)	NAS (1987); Boone et al. (1981); and Rice (1994)
grain	0.47 kg/d (dw)	3.0 kg/d (dw)	NAS (1987); Boone et al. (1981); and Rice (1994)
silage	2.5 kg/d (dw)	4.1 kg/d (dw)	NAS (1987); Boone et al. (1981); and Rice (1994)
soil	0.5 kg/d	0.4 kg/d	Fries (1994); NAS (1987); and Rice (1994)

The total contaminant concentration in the feed items (i.e., forage, silage, and grain) is calculated as a sum of contamination occurring through the following mechanisms:

- *Root uptake - root uptake of contaminants available from the soil and their transfer to the aboveground portions of the plant*

- *Deposition of particles - wet and dry deposition of particle-bound contaminants on plants*

- *Vapor transfer - the vapor phase uptake of the plants through their foliage.*

Vegetation consumed by animals can be classified as protected and unprotected (i.e., not having a protective outer covering). In this analysis, grain is classified as protected feed. Because the outer covering on the protected feed acts as a barrier, contamination of this type of feed product through deposition of particles and vapor transfer is assumed to be negligible. As a result, contamination of grain is assumed to occur only through root uptake. Contamination of forage and silage, unprotected vegetation, is assumed to occur through all three of the above mechanisms.

The methodology used to estimate contamination through vapor transfer considers the reduction of lipophilic contaminant concentrations resulting from mechanisms responsible for inhibiting the transfer of the contaminant. Specifically, the algorithm used to estimate contamination through vapor transfer was developed to estimate the transfer of contaminants into leafy vegetation rather than into bulky aboveground vegetation, such as silage. Because of the shape of bulky aboveground vegetation, transfer of contaminant to the center is unlikely to occur, and as a result, the inner portions will be largely unimpacted. Therefore, applying this algorithm to bulk silage would result in overestimating contaminant concentrations. An adjustment factor (VG_{ag}) has been incorporated into the algorithm to address this overestimation for lipophilic compounds (i.e., compounds with a log K_{ow} value greater than 4), and the VG_{ag} is assigned a value of 0.5 for silage. However, no adjustment is needed to the algorithms for vapor diffusion to forage (i.e. VG_{ag} is equal to 1), since forage can be characterized as leafy vegetation.

5.2.2.5 Concentrations in Pork

For the Tier 3 analysis, subpopulation exposures may include subsistence pork farmers depending on the behavioral activities in the area surrounding the hazardous waste combustor. Therefore, the concentrations in pork may need to be calculated. The contaminant concentrations in pork are estimated based on the amount of contaminant that the hogs are assumed to consume through their diet. Uptake of chemicals via inhalation and ingestion of contaminated water is assumed to be insignificant. For the subsistence pork farmer scenarios, hogs are assumed to have contact with soil. Their diet is assumed to consist of silage, grain, and associated soil; the consumption rate for each of these items is listed in Table 5.7. Each item consumed by hogs is assumed to originate from the site, and therefore the fraction contaminated is assumed to be 1. Equations for calculating contaminant concentration in pork are contained in Appendix B.3.

Table 5.7 Default Consumption Rates of Hogs

Parameter	Pork	References
Consumption of grain	3 kg/d (dw)	U.S.EPA (1990b)
Consumption rate for silage	1.3 kg/d (dw)	U.S. EPA (1990b)
Consumption rate of soil	0.37 kg/d	U.S. EPA (1993a)

The concentration in the feed items (i.e., silage, and grain) is calculated as a sum of contamination occurring through the following mechanisms:

- *Root uptake - root uptake of contaminants available from the soil and their transfer to the aboveground portions of the plant*
- *Deposition of particles - wet and dry deposition of particle-bound contaminants on plants*
- *Vapor transfer - the vapor phase uptake of the plants through their foliage.*

As discussed above for cattle, vegetation consumed by animals can be classified as protected and unprotected (i.e., not having a protective outer covering). For example, grain is classified as protected feed. Because the outer covering on the protected feed acts as a barrier, contamination of this type of feed product through deposition of particles and vapor transfer is assumed to be negligible. As a result, contamination of grain is assumed to occur only through root uptake. Contamination of silage, which is considered unprotected vegetation, is assumed to occur through all three of the above mechanisms.

The methodology used to estimate contamination through vapor transfer considers the reduction of lipophilic contaminant concentrations resulting from mechanisms responsible for inhibiting the transfer of the contaminant. Specifically, the algorithm used to estimate contamination through vapor transfer was developed to estimate the transfer of contaminants into leafy vegetation rather than into bulky aboveground vegetation, such as silage. Because of the shape of bulky aboveground vegetation, transfer of contaminant to the center is unlikely to occur, and as a result, the inner portions will be largely unimpacted. Therefore, applying this algorithm to bulk silage would result in overestimating contaminant concentrations. An adjustment factor (VG_{ag}) has been incorporated into the algorithm to address this overestimation for lipophilic compounds (i.e., compounds with a log K_{ow} value greater than 4). In this analysis, VG_{ag} was assigned a value of 0.5 for silage.

Biotransfer factors for pork are only readily available for certain metals. In the absence of reported biotransfer factors for pork for the remaining chemicals of concern, pork biotransfer factors can be calculated from milk biotransfer factors. As discussed in the dioxin exposure assessment document (U.S. EPA, 1994c), milk biotransfer factors can be converted to beef biotransfer factors by assuming fat contents of beef and milk. This same methodology can be applied by assuming fat content for pork, which is assumed to be 23% (Pennington, 1993). However, the uncertainty associated with estimating pork biotransfer factors based on the relative fat contents of milk and pork cannot be evaluated at this time due to insufficient data on biotransfer in pork.

5.2.2.6 Concentrations in Poultry Meat and Eggs

For the Tier 3 analysis, subpopulation exposures may include subsistence and typical poultry farmers depending on the behavioral activities in the area surrounding the hazardous waste combustor. Therefore, the concentrations in poultry and eggs may need to be calculated. The poultry and egg ingestion pathways are considered only for exposures to dioxins and furans. The contaminant concentrations in poultry and eggs are estimated based on the amount of contaminant that the chickens are assumed to consume through their diet. Uptake of chemicals via inhalation and ingestion of contaminated water is assumed to be insignificant. The chickens considered for the subsistence poultry farm scenario are assumed to have contact with soil, and the contaminant route of exposure for chickens is assumed to be through soil and grain. Chickens are assumed to consume ten percent of their diet as soil, because that percentage is consistent with the study from which the biotransfer factors were obtained (Stephens, et al. 1992). The remainder of the chickens' diet (ninety percent) is assumed to be grain. This methodology is consistent with that applied in the *Risk Assessment Support to the Development of Technical Standards for Emissions from Combustion Units Burning Hazardous Wastes* (U.S. EPA, 1996). The grain contaminant concentration is estimated using the aboveground vegetation algorithm presented in Appendix B.2. Since grain is a protected vegetable, contamination of grain through deposition of particles and vapor transfer is assumed to be negligible. As a result, contamination of grain is assumed to occur only through root uptake. Equations for concentrations in eggs and poultry are contained in Appendix B.3, and the BCF for poultry and eggs are contained in Appendix A for all of the dioxin congeners.

For the typical farmer scenario in the Tier 3 analysis, chickens are assumed to be raised on commercial poultry farms and are not in contact with soil. Therefore, chickens raised by typical farmers are assumed to be only contaminated through grain ingestion. The grain is assumed to originated from the site. Therefore, 100 percent contamination is assumed. The grain contaminant concentration is estimated using the aboveground vegetation algorithm presented in Appendix B.2. Since grain is a protected vegetable, contamination of grain through deposition of particles and vapor transfer is assumed to be negligible. As a result, contamination of grain is assumed to occur only through root uptake.

5.2.2.7 Drinking Water and Fish Concentration

Calculation of contaminant concentration in surface waters and fish is applicable to all three tiers. Surface water concentrations of constituents of concern are calculated for the water bodies identified for consideration in the analyses. Drinking water risks are calculated only for those surface water bodies that are identified as drinking water sources. Five pathways result in contaminant loading of the water body: (1) direct deposition; (2) runoff from impervious surfaces within the watershed; (3) runoff from pervious surfaces within the watershed; (4) soil erosion from the total watershed; and (5) direct diffusion of vapor phase contaminants into the surface water. Other pathways have been omitted or their contributions were assumed to be negligible in comparison with the pathways being evaluated. Appendix B.4 contains the equations used in calculating the concentration in surface water bodies.

Soil erosion from the watershed is often the most significant contributor to the water body concentration. The Universal Soil Loss Equation (USLE) and a sediment delivery ratio are used to estimate the rate of soil erosion from the watershed to the water body. The USLE values and other default parameter values that can be applied in conducting an analysis for the watershed and water body are presented in Table 5.8.

The total concentration of constituents is partitioned between the sediment and the water column. Risks from drinking water ingestion are calculated from the concentrations of constituents dissolved in the water column for each water body identified as a drinking water source. Dissolved concentration is used for drinking water because the water is assumed to be filtered before being sent to homes and consumed.

The constituent concentration that is dissolved in the water column differs from the total water column concentration. The total water column concentration is the summation of the constituent dissolved in the water and the constituent associated with suspended solids. Partitioning between water and sediment varies with the constituent. The equations used to estimate surface water concentrations are presented in Appendix B.4. The results of these equations are used to estimate the concentration of contaminants in fish. The concentrations in fish tissue are estimated using chemical-specific bioconcentration factors (BCFs), bioaccumulation factors (BAFs), or sediment bioaccumulation factors (BSAFs), depending on the chemical. Due to the limited availability of BSAFs, these factors are applied only for dioxins and PCB's. The BCFs, BAFs, and

BSAFs are presented in Appendix A. The equations used to estimate exposures from the ingestion of freshwater fish are presented in Appendix B.4.

Table 5.8 Water body and Watershed Parameters Used to Determine Surface Water Contamination

Parameter	Value	References
USLE soil erodibility factor	0.36 ton/acre	Droppo et al. (1989)
USLE length-slope factor	1.5	U.S.EPA (1988)
USLE cover management factor	0.1	U.S.EPA (1993a)
USLE supporting practice factor	1	U.S.EPA (1993a)
Soil enrichment ratio	3 for organics 1 for metals	U.S.EPA (1993a)
Total suspended solids in water column	10	U.S.EPA (1993a)
Water body temperature	298 K	Assumption; equals 25 °C
Gas phase transfer coefficient	36,500 m/yr	Estimated using gas phase transfer coefficient equation
Depth of benthic upper layer	0.03 m	Based on center of range given in U.S. EPA (1993a)

5.2.2.8 Miscellaneous Parameters Used in Fate and Transport Modeling

Climatological data required for estimating media concentrations using the fate and transport equations include average annual precipitation, average annual ambient air temperature, and mean annual windspeed. These may be available from data recorded onsite, or alternatively may be obtained from the Station Climatic Summary of a nearby airport station without appreciably affecting the outcome of the assessment. Other annual average meteorological parameters used in the media calculations include the evapotranspiration rate and the runoff rate, and these can be obtained from the Water Atlas (Gerghaty, et al. 1973).

6.0 RISK CHARACTERIZATION

This section provides guidance to the permit applicants in characterizing individual risk through the use of health effects criteria or benchmarks and dose estimates calculated for each exposure pathway. For each exposure scenario modeled under each tier, individual risk estimates will need to be calculated. Also, included in this section is a discussion of the uncertainties associated with these types of assessments and a discussion of the uncertainty analysis that should be submitted with each facility's assessment. The specific equations that can be used for calculating doses and risk levels are presented in Appendix C. The health effects criteria or benchmarks are presented in Appendix A.

6.1 Individual Risk Estimation

Individual risk descriptors are intended to convey information about the risk borne by individuals impacted by emissions released by a facility using hazardous waste as fuel in their combustion units. The assessment endpoints that will be calculated under each tier include lifetime cancer risk estimates for carcinogens, hazard quotients and select hazard indexes for non-carcinogens, and exposure levels for lead.

6.1.1 Estimation of Cancer Risk

Under each tier, lifetime cancer risk estimates will need to be calculated for each carcinogenic constituent of concern and for each exposed individual. Once constituent-specific risk estimates are calculated, these risk estimates will need to be summed to estimate total lifetime cancer risk for each exposed individual. The total lifetime cancer risk is to be estimated by aggregating risk across all chemicals and exposure routes (i.e., direct and indirect). However, care must be taken is combining and interpreting risks summed across oral and inhalation routes of exposure since this approach does not necessarily have toxicological foundation due to significant differences in the oral and inhalation pathways. The assumption of additivity is most supported if the carcinogens act systemically (i.e., affecting organs and tissues distant from the portal of entry). Therefore, to allow equal consideration to be given to both direct and indirect risks, both oral and inhalation risks should be presented in addition to the total lifetime cancer risk. The equations that can be used for calculating doses and risk levels are presented in Appendix C. Appendix A identifies which compounds in Tables 4.1 and 4.2 of Section 4 are carcinogens and provides their associated health benchmarks. If additional compounds of concern are identified (i.e., compounds other than those identified on Table 4.1 and 4.2) for consideration in an assessment, health benchmarks for these compounds can be obtained from EPA's IRIS (Integrated Risk Information System) and HEAST (Health Effects Assessment Summary Tables).

6.1.2 Estimation of Potential for Noncancer Effects

Under each tier for each exposed individual, a hazard quotient for each noncancer constituent of concern will be estimated. The resulting hazard quotient represents a comparison of an individual's exposure to some "protective" threshold (i.e., a reference dose (RfD) for oral exposures and reference concentration (RfC) for direct inhalation exposures). Exposures below this threshold are assumed not to result in adverse effects. As exposures increase above the RfD or RfC, the risk of adverse effects increases but to what degree is not known. For constituents that have similar noncarcinogenic effects and effect the same target organ, hazard quotients can be summed across constituents and similar routes of exposure to obtain hazard indices. The equations that can be used for calculating doses and hazard quotients are presented in Appendix C. Appendix A identifies which compounds in Tables 4.1 and 4.2 of Section 4 are noncarcinogens, the target organs that are effected by each compound, and their associated health benchmarks. If additional compounds of concern are identified (i.e., compounds other than those identified on Table 4.1 and 4.2) for consideration in an assessment, health benchmarks for these compound can be obtained from EPA's IRIS (Integrated Risk Information System) and HEAST (Health Effects Assessment Summary Tables).

6.1.3 Estimation of Potential Health Effects for Lead

Because health benchmarks (i.e., RfD, RfC or slope factor) are currently not available for lead risk, estimates can not be estimated as discussed above for other constituents of concern. In the absence of these health benchmarks, alternate methodologies are recommended for assessing risks posed by exposures to lead. Under Tier 1 and 2 assessments, the estimated concentration of lead in soil should be compared to the soil health-based level given in the *Implementation Guidance* which is a concentration of 400 ppm. Under a Tier 3 assessment, human health risks posed by lead will need to be estimated through the use of the uptake/biokinetic model. Specifically, through the use of this model, lead blood levels that would result from human exposures to lead can be estimated and compared to an acceptable level of concern. A computerized version of this model has been developed by the EPA.[15] Because children, rather than adults, are more likely to be exposed to higher levels of lead through their increased consumption rate of soil, it will only be necessary to evaluate indirect risks posed to the children modeled under each of the tiers. However, in evaluating risks posed through direct inhalation childhood and adult exposures to airborne lead should be assessed by comparing the maximum estimated air concentration to the National Ambient Air Quality Standard for lead of 1.5 $\mu g/m^3$.

6.1.4 Infant Exposure Through Breast milk

Infants that are breast-fed are expected to be among the most highly exposed and susceptible human populations to dioxin-like compounds. Therefore, an infant's exposure to 2,3,7,8-TCDD-TEQ through breast milk will need to be evaluated under each tier of the assessment. Appendix C presents the equations that can be used for calculating these exposures. Using these equations, the infant's estimated exposure to 2,3,7,8-TCDD-TEQ through breast milk is estimated based on the mothers estimated exposure for each tier and then is compared to exposures that would result if the mother was exposed at background levels of 2,3,7,8-TCDD TEQ. For comparison, the *Risk Assessment Support to the Development of Technical Standards for Emissions from Combustion Units Burning Hazardous Wastes* (U.S. EPA, 1996) estimates that the average background infant dose is 50 pg/kg/day of 2,3,7,8-TCDD TEQ based on a measured U.S. background level of 16 ppt of TEQ in the lipid portion of breast milk. Exposures over and above background levels are of concern because these exposures may have adverse impact on the developmental biology that may be occurring in humans at or within an order of magnitude of current background exposures (U.S. EPA, 1994c).

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[15] U.S. EPA. 1994. *Guidance Manual for the Integrated Exposure Uptake Biokinetic Model for Lead in Children.* Office of Emergency and Remedial Response.

It should be noted that research is not yet complete in this area for calculating risks posed by dioxin-like compounds to infants. However, until better methods of characterizing breast milk exposure become available, this guidance recommends the use of the methodology discussed above.

6.2 Uncertainty/Limitations

This section discusses the types of uncertainty and the areas where uncertainty can be introduced into an assessment. In addition, this section discusses methods for qualitatively and quantitatively addressing uncertainty in the risk assessments. Each risk assessment should include at a minimum a qualitative discussion of how the uncertainties affect the direction and magnitude of the risk estimates. If possible, the permit applicant should also quantify uncertainties associated with the assessment. Sections 6.2.2 and 6.2.3, respectively, discuss qualitative and quantitative descriptions of uncertainty that can be applied in estimating uncertainty.

Uncertainty can be introduced into a health risk assessment at every step of the process outlined in this document. It occurs because risk assessment is a complex process, requiring the integration of

- *Release of pollutants into the environment*
- *Fate and transport of pollutants in a variety of different and variable environments by processes that are often poorly understood or too complex to quantify accurately*
- *Potential for adverse health effects in humans as extrapolated from animal bioassays*
- *Probability of adverse effects in a human population that is highly variable genetically, in age, in activity level, and in life style.*

Even using the most accurate data with the most sophisticated models, uncertainty is inherent in the process. The methodology outlined in this document rely on a combination of point values -- some conservative and some typical, yielding a point estimate of exposure and risk that falls at an unknown percentile of the full distributions of exposure and risk. For this reason, the degree of conservatism in risk estimates cannot be known -- only that the values combine many conservative factors and are likely to overstate actual risk (Hattis and Burmaster, 1994). Therefore, a formal uncertainty analysis is required to determine the degree of conservatism.

6.2.1 Types of Uncertainty

Finkel (1990) classified all uncertainty into four types (parameter uncertainty, model uncertainty, decision-rule uncertainty, and variability) which are summarized in Table 6-1. The first two, parameter uncertainty and model uncertainty, are generally recognized by risk assessors as major sources of uncertainty.

Table 6.1 Sources of Uncertainty in Risk Assessment*

General Type	Specific Source of Uncertainty	Comments/Examples
Parameter uncertainty	Measurement errors	• include limitations of equipment, methodology, and human error • some processes impossible to measure exactly
	Random errors	• sampling errors • can be minimized by increasing sample size
	Systematic errors	• nonrandom errors • result of inherent flaw in data gathering processes • minimize by external peer review
Model uncertainty	Surrogate variables	• e.g., use of animal bioassays to determine effect on humans
	Excluded variables	• may result from model simplification or failure to recognize an important variable
	Abnormal conditions	• e.g., failure to recognize importance of episodic meteorological events
	Incorrect model form	• e.g., choice of dose-response model for carcinogens
Decision-rule uncertainty		• more important for risk management, but need to recognize that value judgments affect choice of model and interpretation of results
Variability		• those important for health risk assessment include sources of pollutant releases, environmental factors, genetic variability, and lifestyle differences • even if variability is known (therefore, not in itself uncertain) it still contributes to overall uncertainty of the risk assessment

*Adapted from Finkel, 1990.

Parameter uncertainty occurs when parameters appearing in equations cannot be measured precisely and/or accurately either because of equipment limitations or because the quantity being measured varies spatially or temporally. Random, or sample errors, are a common source of parameter uncertainty that is especially critical for small sample sizes. More difficult to recognize are nonrandom or systematic errors that result from bias in sampling, experimental design, or choice of assumptions.

Model uncertainty is associated with all models used in all phases of a risk assessment. These include the animal models used as surrogates for testing human carcinogenicity, dose-response models used in extrapolations, as well as the computer models used to predict the fate and transport of chemicals in the environment. The use of rodents as surrogates for humans introduces uncertainty into the risk factor since there is considerable interspecies variability in sensitivity. Computer models are simplifications of reality, requiring exclusion of some variables that influence predictions but cannot be included in models due either to increased complexity or to a lack of data on that parameter. The risk assessor needs to consider the importance of excluded variables on a case-by-case basis, because a given variable may be important in some instances and not in others. A similar problem can occur when a model that is applicable under average conditions is used for a case where conditions differ from the average. Finally, choosing the correct model form is often difficult because conflicting theories seem to explain a phenomenon equally well. The models specified for use in this document were selected based on science policy. Thus, the air dispersion and deposition model and the indirect exposure models were selected because they provide the information needed for conducting indirect assessments and are considered by the Agency to be state-of-the-science. This choice of models could also be considered under decision rule uncertainty. The air dispersion model recommended for use, ISCST3 has not been widely applied in the present form. Few data are available on atmospheric deposition rates for chemicals other than criteria pollutants, making the selection of input parameters related to deposition and validation of modeled deposition rates difficult. Because dry deposition of vapor phase materials is evaluated external to the air dispersion model, the plume is not depleted and, therefore, mass balance is not maintained. The effect of this would be to overestimate deposition but the magnitude of the overestimation is unknown. Mass balance is maintained for other forms of deposition (i.e., wet deposition and particle phase dry deposition). Long range transport of pollutants into and out of the areas considered are not modeled. The result is the underestimation of risk attributable to each facility.

The third type, decision-rule uncertainty, is probably of more concern to risk managers. This type of uncertainty arises, for example out of the need to balance different social concerns when determining an acceptable level of risk. There are a number of policy and risk management decisions that have an influence on the uncertainty of a risk analysis. Possibly the most important aspect for the risk estimates, is the selection of constituents to be included in the analysis. The constituents that will be identified based on guidance provided in this document will include compounds that have the potential to pose the greatest risk to human health through indirect exposure routes. For example, many PICs are highly lipophilic and tend to bioaccumulate in the food chain thus presenting potentially high risk through the consumption of contaminated food. A second area of decision-rule uncertainty includes the use of standard EPA default values in the analysis. These include inhalation and consumption rates, body weight, and lifetime, which are standard default values used in most EPA risk assessments. Inhalation and consumption rates are highly correlated to body weight for adults. Using a single point estimate for these variables instead of a joint probability distribution ignores a variability that may influence the results by up to a factor of two or three. A third area of decision-rule uncertainty is the use of Agency-verified cancer slope factors, reference doses and reference concentration. These health benchmarks are used as single point estimates throughout the analysis. These benchmarks have both uncertainty and variability associated with them. However, the Agency has developed a process for setting verified health benchmark values to be used in all Agency risk assessments. With the exception of the dioxin and PAH toxicity equivalency methodologies, all health benchmarks recommended for use in all analyses are verified through the Agency's work groups and available on the Agency's Integrated Risk Information System. No estimation of the uncertainty in the use of the Agency's verified health benchmarks or the toxicity equivalency methodologies will be made here.

Variability, the fourth source of uncertainty, is often used interchangeably with the term "uncertainty," but this is not strictly correct. Variability may be tied to variations in physical and biological processes and cannot be reduced with additional research or information, though it may be known with greater certainty (e.g., age distribution of a population may be known and represented by the mean age and its standard deviation). "Uncertainty" is a description of the imperfection in knowledge of the true value of a particular parameter or its real variability in an individual or a group. In general, uncertainty is reducible by additional information-gathering or analysis activities (better data, better models), whereas real variability will not change (although it may be more accurately known) as a result of better or more extensive measurements (Hattis and Burmaster, 1994).

6.2.2 Qualitative Description of Uncertainty

Often, the sources of uncertainty in a risk assessment can be determined, but they cannot be quantified. This can occur when a factor is known or expected to be variable, but no data are available (e.g., the amount of time people at a specific site spend out of doors). In this case, sometimes default data are available that can be useful for estimating a possible range of values. Uncertainty often arises out of a complete lack of data. A process may be so poorly understood that the uncertainty cannot be quantified with any confidence. In addition, some sources of uncertainty (such as uncertainty in theories used to deduce models) are inherently qualifications reflecting subjective modes of confidence rather than probabilistic arguments. When uncertainty can only be presented qualitatively, the possible direction and orders of magnitude of the potential error should be considered.

6.2.3 Quantitative Description of Uncertainty

Knowledge of experimental or measurement errors can also be used to introduce a degree of quantitative information into a qualitative presentation of uncertainty. For example, standard laboratory procedures or field sampling methods may have a known error level that can be used to quantify uncertainty. In many cases, the uncertainty associated with particular parameter values or for the estimated risks can be expressed quantitatively. Finkel (1990) identified a six-step process for producing a quantitative uncertainty estimate:

- *Define the measure of risk (e.g., deaths, life-years lost, maximum individual risk (MIR), population above an "unacceptable" level of risk). More than one measure of risk may result from a particular risk assessment; however, the uncertainty should be quantified for each individually.*

- *Specify "risk equations" that present the mathematical relationships that express the risk measure in terms of its components. This step is used to identify the important parameters in the risk estimation process.*

- *Generate an uncertainty distribution for each parameter or equation component. These uncertainty distributions may be generated by the use of analogy, statistical inference techniques, or elicitation of expert opinion, or some combination of these.*

- *Combine the individual distributions into a composite uncertainty distribution. Monte Carlo simulation, frequently used for this step, is discussed in greater detail later in this section, and was used in this analysis.*

- *Recalibrate the uncertainty distributions. Inferential analysis could be used to "tighten" or "broaden" particular distributions to account for dependencies among the variables and/or to truncate the distributions to exclude extreme values.*

- *The output should be summarized in a manner that is clear and highlights the important risk management implications. Specific factors should be addressed including: the implication of supplanting a point estimate produced without considering uncertainty, the balance of the costs of under- or overestimating risks, unresolved scientific controversies, and implications for research.*

When a detailed quantitative treatment of uncertainty is required, statistical methods are employed. Two approaches to a statistical treatment of uncertainty with regard to parameter values are described here and should be used in an analysis where appropriate. The first is simply to express all variables for which uncertainty is a major concern using an appropriate statistic. For example, if a value used is from a sample (e.g., emissions from a stack), both the mean and standard deviation should be presented. If the sample size is very small, it may be appropriate to give the range of sample values and use a midpoint as a best estimate in the model; or, both the smallest and largest measured value could be used to get two estimates that bound the expected true value. The appropriate statistic to use depends on the amount of data available and the degree of detail required. Uncertainties can be propagated using analytical or numerical methods.

A second approach is to use the probability distributions of major variables to propagate parameter value uncertainties through the equations used in a risk analysis. A probability distribution of expected values is developed for each parameter value. These probability distributions are typically expressed as either probability density functions (PDF) or as cumulative probability density functions (CPF). The PDF presents the relative probability for discrete parameter values while the CPF presents the cumulative probability that a value is less than or equal to a specific value.

Uncertainties are propagated by developing a composite uncertainty distribution by combining the individual distributions with the equations used to calculate probability of cancer. Numerical methods are often employed for this phase, with Monte Carlo simulations gaining wide acceptance for this purpose. In Monte Carlo simulations, a computer program (e.g., Crystal Ball) is used to repeatedly solve the model equations under different selections of parameter values to calculate a distribution of exposure (or risk) values. Each time the equations are calculated, values are randomly sampled from the specified distributions for each parameter. The end result is a distribution of exposure (or risk). These can again be expressed as PDFs or, more appropriately, as CPFs. The distribution allows the risk assessor to choose the value corresponding to the appropriate percentile in the overall distribution. For example, an exposure level or risk level can be selected that corresponds to the 95th percentile of the overall risk distribution rather than relying on a point estimate of risk based on the 95th percentile values for each parameter. This allows the risk analyst to reflect quantitatively the confidence of that risk estimate with respect to the range of possible risks.

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