PART III

HUMAN HEALTH RISK ASSESSMENT: MULTIPATHWAY

Chapter 14 Overview and Getting Started: Planning and Scoping the Multipathway Risk Assessment

Table of Contents

14.1 Introduction

Part II of this Reference Manual discussed how to plan for and conduct a human health risk assessment via the direct inhalation pathway. Part III provides the same general discussion of the various aspects of the risk assessment process; however, the discussion is focused specifically on multipathway human health risk assessment. ***As noted earlier, all air toxics risk assessments evaluate the direct inhalation pathway. In addition, multipathway risk assessment may be appropriate generally when air toxics that persist and which also may bioaccumulate and/or biomagnify are present in releases. These generally will focus on the persistent bioaccumulative hazardous air pollutant (PB-HAP) compounds (Exhibit 14-1), but specific risk assessments may need to consider additional chemicals that persist and which also may bioaccumulate and/or biomagnify***. For these compounds, the risk assessment generally will need to consider exposure pathways other than inhalation – in particular, pathways that involve deposition of air toxics onto soil and plants and into water, subsequent uptake by biota, and potential human exposures via consumption of contaminated soils, surface waters, and foods. Substances that persist and bioaccumulate readily transfer between the air, water, and land. Some may travel great distances, and linger for long periods of time in the environment.

The discussion of multipathway risk assessment follows the same general framework presented in Part II. This chapter presents an overview of multipathway risk assessment and discusses the initial planning, scoping and problem formulation activities. The remaining chapters of this Part focus on Exposure Assessment (Chapters 14 to 20), Toxicity Assessment (Chapter 21), and Risk Characterization (Chapter 22). The discussions presented here supplement the information provided earlier – readers are encouraged to refer back to the corresponding Chapters in Part II for additional background materials.

Bioconcentration is the net accumulation of a substance by an organism as a result of uptake directly from an environmental medium (e.g., net accumulation by an aquatic organism as a result of uptake directly from ambient water, through gill membranes or other external body surfaces).

Bioaccumulation is the net accumulation (storage in tissue and/or organs) of a substance by an organism as a result of uptake from all environmental sources – the medium in which they live, the water they drink, and the diet they consume – over a period of time.

Biomagnification or Biological Magnification is the process whereby certain substances, such as pesticides or heavy metals, transfer up the food chain and increase in concentration. A biomagnifying chemical deposited in rivers or lakes absorbs to algae, which are ingested by aquatic organisms, such as small fish, which are in turn eaten by larger fish, fish-eating birds, terrestrial wildlife, or humans. The chemical tends to accumulates to higher concentration levels with each successive food chain level. Biomagnification is illustrated in Chapter 23.

Exhibit 14-1. PB-HAP Compounds			
PB-HAP Compound	**Pollution Prevention Priority PBTs**	**Great Waters Pollutants of Concern**	**TRI PBT Chemicals**
Cadmium compounds		X	
Chlordane	X	X	X
Chlorinated dibenzodioxins and furans	X[(a)]	X	X[(b)]
DDE	X	X	
Heptachlor			X
Hexachlorobenzene	X	X	X
Hexachlorocyclohexane (all isomers)		X	
Lead compounds	X[©)]	X	X
Mercury compounds	X	X	X
Methoxychlor			X
Polychlorinated biphenyls	X	X	X
Polycyclic organic matter	X[(d)]	X	X[(e)]
Toxaphene	X	X	X
Trifluralin			X

[(a)] "Dioxins and furans" ("" denotes the phraseology of the source list)
[(b)] "Dioxin and dioxin-like compounds"
[(c)] Alkyl lead
[(d)] Benzo[a]pyrene
[(e)] "Polycyclic aromatic compounds" and benzo[g,h,i]perylene
See Appendix D for a discussion of the derivation of this list of PB-HAPs.

14.2 Overview of Multipathway Air Toxics Risk Assessment

The multipathway risk assessment is organized in the same way as the direct inhalation risk assessment into three general phases:

1. Planning, scoping, and problem formulation;
2. Analysis, consisting of exposure assessment and toxicity assessment; and
3. Risk characterization.

14.2.1 Planning, Scoping, and Problem Formulation

The planning, scoping, and problem formulation phase of multimedia risk assessment focuses on developing a common understanding of what needs to be added to the risk assessment (beyond the direct inhalation assessment) to assess risks associated with pathways involving deposition (i.e., transfer of the compounds to soil, water, sediment, and biota) and subsequent ingestion exposure. The scope of the multimedia risk assessment generally is more extensive than that for inhalation assessment, and therefore significant additional effort is likely.

For purposes of this Reference Manual, we discuss planning, scoping, and problem formulation for multipathway human health risk assessment separately from the corresponding phase for inhalation risk assessment. In reality, the planning, scoping, and problem formulation phase for the multipathway assessment would be integrated with the inhalation analysis as early as feasible.

It may be necessary to include on the **planning and scoping team** experts in multimedia modeling, bioaccumulation, human exposure factors, and ingestion toxicology. The focus on additional exposure pathways may influence many aspects of the risk assessment, including the size of the study area; emission sources to be considered; the temporal and spatial resolution required; the appropriate level of detail and documentation; trade-offs between depth and breadth in the analysis; QA/QC requirements; analytical approaches to be used; and the staff and monetary resources to commit. The **study-specific conceptual model** would also reflect the specific concerns of air toxics that persist and which also may bioaccumulate. As with the inhalation risk assessment, the planning, scoping, and problem formulation process is an iterative process that reflects changing information and concerns as the multimedia risk assessment unfolds.

The reader should become familiar with Part II of this manual before reading this Part, since Part III focuses primarily on those aspects of the risk assessment that are unique to multipathway analyses, including:

- How the study area is defined;
- Potentially exposed populations;
- Exposure pathways and exposure routes;
- How exposure is assessed;
- Dose-response values for non-inhalation pathways; and
- How risks are characterized.

14.2.2 Analysis

The analysis phase of the multipathway assessment is divided into two components: exposure assessment and toxicity assessment. **Exposure assessment** is likely to be considerably more complicated than the corresponding inhalation exposure assessment for several reasons:

- People can be exposed to air toxics in many more ways, including in the food they eat, the milk they drink, and the soils on which they play.

- Time is a critical variable. Air toxics that persist and which also may bioaccumulate can slowly build up in soils, sediments, and biota over time. With sufficient time, even relatively small releases have the potential to result in high exposures.

- The spatial distribution of the air toxics can be complex. Chemicals can move away from deposition points due to runoff, erosion, and the movement of contaminated animals. Chemicals deposited over a wide area (e.g., a watershed) can concentrate in smaller areas (e.g., a pond).

- Multimedia models often use more extensive input variables.

- Sampling and analysis may involve a wider range of media (e.g., soil, sediment) and different types of biota (e.g., fish, shellfish, plants). Each type of sampling and analysis has its own methods, protocols, and QA/QC procedures.

- Whereas the exposure concentration in air is the quantitative metric of exposure for inhalation, intake is the quantitative metric of ingestion exposure in multipathway analyses. To quantify intake, it is necessary to (1) estimate the concentrations of chemicals of potential concern (COPC) in water, soil, sediment, and/or food items; (2) determine how much water, soil, sediment, and food are ingested; (3) determine the duration and temporal patterns over which ingestion occurs; and (4) adjust for body weight, to account for the different types of people in the population who interact with the contaminated media. Multimedia exposure assessment uses a number of different **exposure factors** that provide quantitative estimates of the physical and behavioral attributes of potentially exposed populations (e.g., how much fish a person eats per day). Exposure factors can be treated as either constants or variables in the exposure assessment, depending on whether a deterministic or probabilistic analysis is being performed.

The multipathway **toxicity assessment** is similar to the toxicity assessment for inhalation. It considers the same general information: (1) the types of potential adverse health effects associated with chemical exposures; (2) dose-response relationships; and (3) related uncertainties such as the weight of evidence for carcinogenic effects. There are two primary differences:

- A chemical's toxicity is influenced by the route of exposure. That is, the same chemical can result in different toxic effects (and have different dose-response values) depending on whether the chemical is inhaled or ingested. There are a number of reasons why this may occur. For example, when a chemical is inhaled into the respiratory tract, the primary toxic effect may occur in the respiratory tract as a result of the inhaled chemical (a portal of entry effect). When swallowed, on the other hand, many chemicals are absorbed into the bloodstream through the gastrointestinal tract where they are carried directly to the liver. Chemicals in the liver are often metabolized extensively (either to more or less toxic substances) before being transported by the bloodstream to other parts of the body.

- The specific dose-response values used for the ingestion pathway – reference doses (RfDs) for non-cancer effects and oral cancer slope factors (CSFs) – differ in form and derivation from those used for inhalation assessments. Specifically, RfDs and CSFs are developed to match the metric of exposure for ingestion and are expressed (usually) in terms of amount of chemical ingested per unit of body weight per day (i.e., mg/kg-d for RfDs) and risk per amount of chemical ingested per unit body weight per day (i.e., $(mg/kg\text{-}d)^{-1}$ for CSFs).

14.2.3 Risk Characterization

The risk characterization for multipathway assessments also may be more complicated than that for the inhalation risk assessment.

- Ingestion risk estimates are first added across all ingestion pathways and then added to inhalation risk estimates to calculate total (i.e., cumulative) risk. Although the summation process is relatively simple for screening-level analyses, it can become complex for more advanced tiers of risk assessment.

- The uncertainty analysis for multipathway risk assessments may be considerably more complex if multiple pathways are important because many more exposure factors and variables will be involved in the quantification of risk. As noted earlier, many more specific exposure factors can be treated as variables for probabilistic multipathway risk assessments.

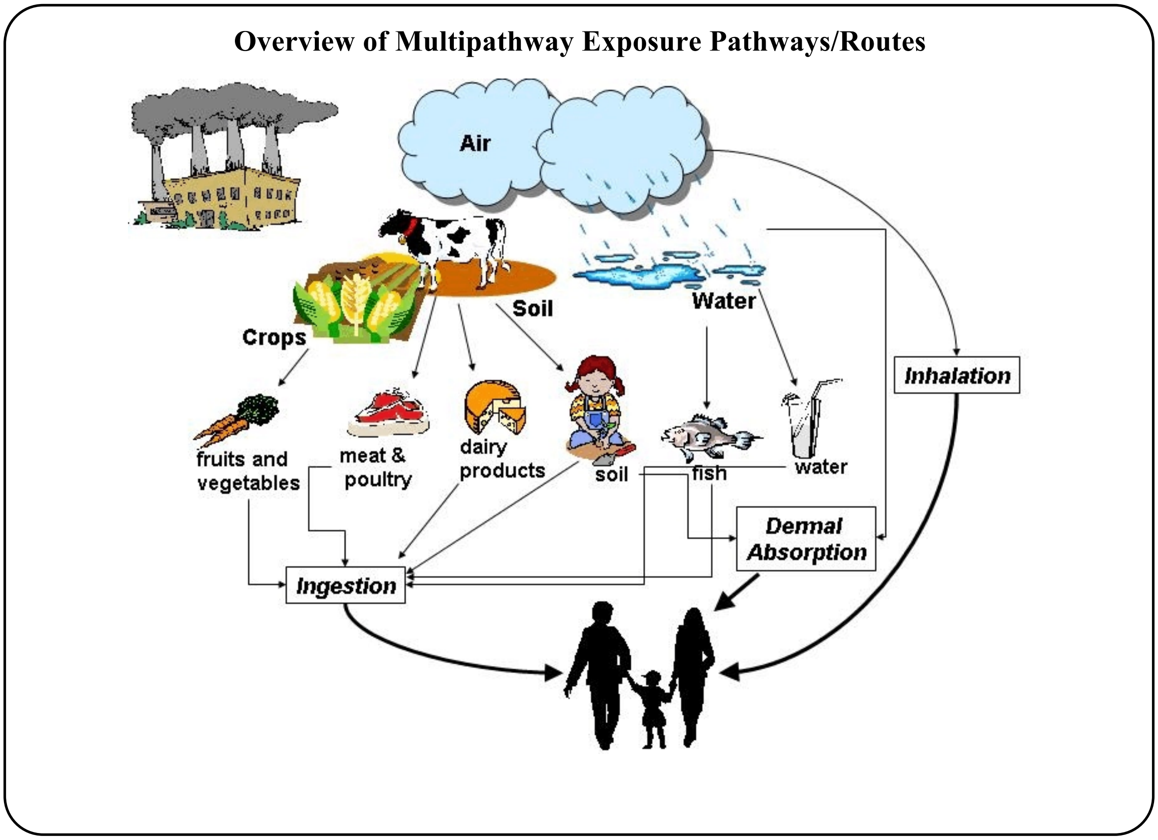
- The uncertainty analysis for multipathway analysis is also much more complex due to the larger number of pathways assessed and the larger number of measurement and modeling inputs that are needed.

14.3 Overview of Multipathway Exposure Assessment

As with inhalation risk assessments, the exposure assessment for multipathway risk assessments includes identifying sources, characterizing releases to the air, estimating concentrations of air toxics in the environment, characterizing potentially exposed populations, and developing metrics of exposure. This section provides an overview of exposure assessment for multipathway risk assessments. Familiarity with EPA's *Guidelines for Exposure Assessment*[1] prior to beginning the multipathway exposure assessment would be helpful.

The multipathway exposure assessment covers a broader scope and may be more complex than direct inhalation exposure assessment.

- Exposure pathways to be evaluated include multiple media (soil, water, sediment, biota) and exposure routes in addition to inhalation (e.g., ingestion). Therefore, the exposure setting may need additional characterization (e.g., the location and nature of water bodies and/or agricultural crops).



- The evaluation of chemical fate and transport accounts for the transfer of contaminants from air to soil and water and subsequent transport and transfer to other media. For example, air toxics that persist and which also may bioaccumulate are deposited onto soils and can enter surface waters via runoff; some of the compounds that deposit into water predominantly partition into sediments. **Bioaccumulation** – a concentration of contaminants in biological tissues – and subsequent transfer to humans via ingestion often play a major role in the exposure assessment. Multimedia models can be used to describe contaminant fate and transport through the use of partition coefficients and mass-balance techniques (see Chapter 6). Different monitoring methods (e.g., sediment or fish tissue sampling and analysis) may be included to augment or assist in the evaluation of modeling outputs.

- In contrast to the direct inhalation assessment, in which the quantitative metric of exposure is the ambient air concentration at the exposure point, ingestion exposures are quantified using the **chemical intake rate** – the amount of chemical ingested per unit time – generally expressed in units of milligrams of chemical per kilogram of body weight per day. Calculation of chemical intake rate requires information on COPC concentrations in items ingested as well as information about the type and amount of different items eaten each day, body weight, and exposure durations for the sub-populations of interest. **Intake rate** is simply the amount of food (or other media), containing the contaminant of interest, that an individual ingests during some specific time period (units of mass/time). Intake rate can be expressed as a total amount (e.g., mg); as a dose rate (e.g., mg/day); or as a rate normalized to body mass (e.g., mg/kg-day). For most chemicals, the dose-response value (e.g., reference dose, or RfD) is based on the potential dose (i.e., the amount of chemical taken in), with no explicit correction for the fraction absorbed. For some chemicals, it may be necessary to adjust for such differences using physiologically based pharmacokinetic (PB-PK) models, mathematical dosimetry models, and/or adjustment factors (see Chapter 8).

Because exposure is quantified using chemical intake rate, different types of people within a population (e.g., childhood exposures) may need to be considered explicitly. Consumption rates, dietary preferences, and body weight vary with age and would be accounted for in the risk assessment. (Note that not only age, but sex, ethnicity, cultural and religious practices may also strongly influence the exposure patterns of people within a potentially exposed population.)

Although it is possible to evaluate acute exposures for the ingestion pathway, EPA does not generally perform acute exposure assessments, because it is unlikely that PB-HAP compounds would concentrate to acutely toxic levels under any typical release scenario that did not pose a much more substantial chronic risk. However, each assessment would consider the available evidence in making this judgement. At a minimum, the risk characterization would state the reasons why an analysis of acute health effects for non-inhalation pathways was not performed.

The multipathway exposure assessment focuses on two general categories of ingestion pathways: incidental ingestion and food chain (Exhibit 14-2). Incidental ingestion pathways consider exposures that may occur from ingestion of soils or surface water while an individual is engaged in other activities (e.g., ingestion of soil while gardening or playing outside; ingestion of surface water while swimming). Food chain pathways consider exposures that may occur if PB-HAP compounds accumulate in the food and water people consume.

Exhibit 14-2. Human Exposure Pathways Considered for Multipathway Air Toxics Assessments

Incidental Ingestion Pathways:

air → soil → human
air → surface water → human

Food Chain Pathways:

air → water → human
air → soil → water → human
air → vegetation → human
air → animal → human
air → vegetation → animal → human
air → soil → vegetation → human
air → soil → animal → human
air → soil → water → animal → human
air → soil → water → fish → human
air → soil → water → sediment → fish → human
air → water → animal → human
air → water → fish → human
air → water → sediment → fish → human

As Exhibit 14-2 suggests, the focus of the multipathway assessment is on ingestion pathways. Other exposure pathways may be important for particular risk assessments, including dermal exposures (i.e., direct contact with contaminated soils, surface waters, or surface water sediments during outside activities such as gardening or swimming); resuspension of dust (e.g., from wind blowing across contaminated soils, or agricultural activities such as tilling) and subsequent inhalation of the dust particles; and ingestion of contaminated groundwater. However, EPA does not have sufficient experience with multipathway air toxics risk assessments to identify the circumstances for which exposures via these additional pathways may represent a potential concern.

- If site-specific circumstances suggest that dermal pathways may be of concern, EPA's *Risk Assessment Guidance for Superfund (RAGS), Part D, Standardized Planning, Reporting and Review of Superfund Risk Assessments*,(2) includes a relatively straightforward methodology for dermal exposure and risk assessment, starting with soil concentrations. The Planning Tables in the document are simple to use and incorporate into the multipathway analysis.

- Relative to the direct inhalation pathway, inhalation of soil resulting from dust resuspension by wind erosion generally is not thought to be a significant pathway of concern for air toxics risk assessments. If site-specific circumstances suggest that resuspension of dust may represent a potential concern, EPA's *Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combuster Emissions* (MPE) (Chapter 5 Dust Resuspension) discusses the methods for evaluating this pathway.(3)

Analysis of Groundwater Pathways

EPA's Office of Solid Waste has considerable experience in modeling and monitoring the movement of contaminants in groundwater. Much of that experience is based on exposure assessments associated with land-based disposal units (i.e., where the source of contamination is in the subsurface). For example, EPA's Center for Exposure Assessment Modeling (CEAM) distributes multimedia models designed to quantify the movement and concentration of contaminants (from land-based releases at hazardous waste sites) traveling through groundwater, surface water, and food chain media (available at http://www.epa.gov/ceampubl/). In these models, releases to the atmosphere from the subsurface may be considered, but transfer from the air through the subsurface are not.

EPA does not have sufficent experience with air toxics multipathway analysis to identify situations in which the groundwater may be contaminated. EPA's *Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure*(3) identifies three site-specific conditions that might lead to greater groundwater impacts:

- Deposition rates that are several times greater than the average;
- The existence of more soluble HAPs in emissions; and
- Higher recharge rates such as would occur in areas with very permeable soil and bedrock near the surface.

- If site-specific circumstances suggest that groundwater may represent a potential concern (e.g., the presence of extremely shallow aquifers used for drinking water purposes or a karst environment in which the local surface water significantly affects the quality of ground water used as a drinking water source), Total Risk Integrated Methodology - Fate, Transport, and

Ecological Exposure Module (TRIM.FaTE) has the ability to assess chemicals moving into the groundwater pathway. EPA's *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities*[3] and EPA's *Draft Technical Background Document for Soil Screening Guidance* discusses methods for evaluating the groundwater pathway.

14.4 Planning and Scoping

As with inhalation analyses, the key steps in the planning and scoping process include (1) identifying the concern; (2) identifying who will be involved; (3) determining the scope of the risk assessment; (4) describing why there may be a problem; and (5) determining how the concern will be evaluated. The planning and scoping process for multipathway risk assessment focuses on developing a common understanding of what needs to be evaluated to assess risks via deposition and transfer of the air toxics to soil, water, and biota, and subsequent ingestion. More detailed discussions of the planning and scoping process can be found in Part II of this Volume and in guidance documents developed by EPA.[4]

14.4.1 Identifying the Concern

The driving concern for the multipathway risk assessment generally would be the same as that for the inhalation risk assessment (e.g., regulatory requirement, community need, health concern). However, a number of additional specific concerns may arise. For example, the potential for bioaccumulation in food and subsequent ingestion may raise specific concerns about areas where people farm, economic issues such as recreational fishing, or additional exposure pathways of potential concern (e.g., infants ingesting mother's milk).

14.4.2 Identifying the Participants

The participants for the multipathway risk assessment generally would be the same as those for the inhalation risk assessment. However,

- A broader range of risk managers would be involved. For example, if there is a potential for a fishery or farm crops to become contaminated with air toxics, different persons or groups may have the authority to make the risk management decisions – the state, local, or tribal (S/L/T) fish and game department or the agriculture department may become involved.

- The risk assessment technical team would include additional experts (e.g., in the areas of multimedia modeling, bioaccumulation, soil chemistry).

- The specific set of interested or affected parties may change or expand (e.g., farmers and fishermen may be more concerned/involved).

14.4.3 Determining the Scope of the Risk Assessment

At a minimum, the scope of the risk assessment will include additional exposure pathways, exposure routes, and potentially exposed populations or sub-populations. The details of scope are developed during the problem formulation step (see Chapter 15).

14.4.4 Describing the Problem

As with inhalation, participants would develop a **problem statement** that clearly articulates the perceived problem to be evaluated. The problem statement may also provide statements of what is and is not included in the multipathway risk assessment and why. (Note that, in general, only one problem statement is necessary to describe all exposure pathways, including inhalation. A separate problem statement for each exposure pathway is not usually necessary.)

14.4.5 Determining How Risk Managers Will Evaluate the Concern

As with inhalation, the multipathway risk assessment would be designed to provide input to risk managers to help inform the decisions they must make. Part of the planning and scoping process is developing an understanding of the types of information needed by the risk managers and the level of uncertainty in that information that can be tolerated.

Example Multipathway Problem Statement

Air toxics emissions may be causing increased long-term health risk to people who eat fish in Puffer Pond that may be contaminated with mercury compound releases from the Big Air Manufacturing Company. A multipathway risk assessment will be performed to evaluate potential long-term human health impacts associated with consumption of contaminated fish. Ingestion risks will be assessed for recreational fishers who eat fish caught in Puffer Pond. In addition, a modeling risk assessment using air dispersion modeling will be conducted to estimate inhalation risks for populations within 50 km of the Acme property boundary using residential exposure conditions.

14.5 Tiered Multipathway Risk Assessments

EPA guidance generally recommends that a tiered approach to risk assessments be taken to identify the key chemicals, sources, and pathways that contribute most to the risk being evaluated.[5] A tiered approach can be particularly valuable for multipathway risk assessments because of the potential complexity commonly associated with such analyses. Often, screening-level analyses assume relatively high exposure factors (e.g., all of the fish a person eats comes from a potentially contaminated pond) to determine whether risk associated with a specific pathway appears to be significant enough to warrant more robust analysis. Subsequent tiers of analysis, using more realistic exposure factors and perhaps involving more complex modeling and perhaps sampling and analysis, are generally undertaken only if lower-tier analyses continue to indicate the potential for risk. As with inhalation risk assessments, an iterative process of evaluation, deliberation, data collection, work planning and communication is used to decide:

- Whether or not the risk assessment, in its current state, is sufficient to support the risk management decision(s); and
- If the assessment is determined to be insufficient, whether or not progression to a higher tier of complexity (or refinement of the current tier) would provide a sufficient benefit to warrant the additional effort.

References

1. U.S. Environmental Protection Agency. 1992. *Guidelines for Exposure Assessment. Federal Register* 57:22888-22938, May 29, 1992. Available at http://cfpub.epa.gov/ncea/raf/recordisplay.cfm?deid=15263

2. U.S. Environmental Protection Agency. 2001. *Risk Assessment Guidance for Superfund (RAGS): Volume I - Human Health Evaluation Manual (Part D, Standardized Planning, Reporting and Review of Superfund Risk Assessments), Final*. Office of Emergency and Remedial Response, Washington, D.C., December 2001. EPA 9285.7-47.

3. U.S. Environmental Protection Agency. 1998. *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities, Peer Review Draft*. Office of Solid Waste and Emergency Response, July 1998. EPA/530/D-98/001 A, B, and C and subsequent Errata (EPA Memo, July 1999). Available at: http://www.epa.gov/earth1r6/6pd/rcra_c/pd-o/comb_risk.htm

4. U.S. Environmental Protection Agency. 1997. *Guidance on Cumulative Risk Assessment. Part 1. Planning and Scoping.* Science Policy Council, Washington, D.C., July 3, 1997. Available at: http://www.epa.gov/osp/spc/cumrisk2.htm

   U.S. Environmental Protection Agency. 2003. *Framework for Cumulative Risk Assessment*. Office of Research and Development, National Center for Environmental Assessment, Washington, D.C., 2003. EPA/600/P-02/001F. Available at: http://cfpub.epa.gov/ncea/raf/recordisplay.cfm?deid=54944

   U.S. Environmental Protection Agency. 2001. *Risk Assessment Guidance for Superfund (RAGS): Volume I - Human Health Evaluation Manual (Part D, Standardized Planning, Reporting and Review of Superfund Risk Assessments) Final.* Office of Emergency and Remedial Response, Washington, D.C., December 2001. Publication 9285.7-47. Available at: http://www.epa.gov/superfund/programs/risk/ragsd/index.htm

5. U.S. Environmental Protection Agency. 2001. *Risk Assessment Guidance for Superfund (RAGS). Volume III - Part A. Process for Conducting Probabilistic Risk Assessment*. Office of Emergency and Remedial Response, Washington, D.C., December 2001. EPA/540/R-02/002. Available at: http://www.epa.gov/superfund/programs/risk/rags3a/index.htm