Chapter 15 Problem Formulation: Multipathway Risk Assessment

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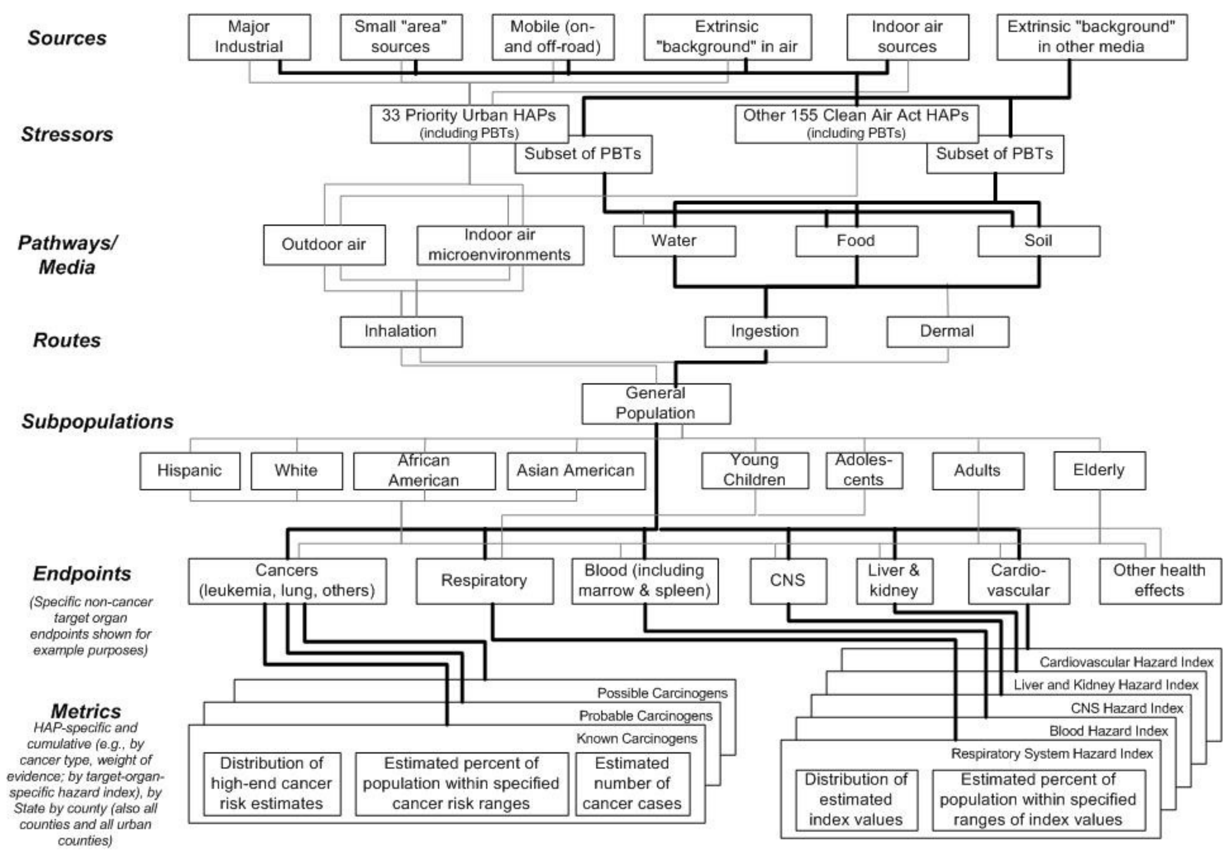
15.1 Introduction

This chapter discusses the problem formulation step of the multipathway risk assessment, which takes the results of the planning and scoping process and translates them into two critical products: the conceptual model, and the analysis plan.

15.2 Developing the Multipathway Conceptual Model

As with inhalation analyses, the conceptual model (Exhibit 15-1) focuses the multipathway risk assessment on several key elements, including sources, chemicals released, fate and transport mechanisms, potentially exposed populations, potential exposure pathways and routes of exposure, and potential adverse effects. Although discussed separately here, as noted in Chapter 6, ***the elements of the conceptual model that are unique to the multipathway human health risk assessment should be integrated with those for the inhalation assessment as early as feasible***.

Exhibit 15-1. Generalized Conceptual Model for Multipathway Analyses



This figure highlights the multipathway components of the general air toxics risk assessment conceptual model introduced in Chapter 6. The conceptual model for a specific multipathway risk assessment may consider only part of this general model, or may focus more closely on specific sub-populations of concern.

Elements of the conceptual model that may be unique to the multipathway assessment include:

- **Sources**. The specific sources included in the analysis may be focused on the subset of all sources that release most or all of the identified air toxics that persist and which also may bioaccumulate.

- **Chemicals of potential concern**. The specific COPC will focus on those air toxics that persist and which also may bioaccumulate (i.e., persistent bioaccumulative hazardous air pollutants (PB-HAPs) and other non-HAP chemicals that may be of concern for persistence and bioaccumulation).

- **How the COPC move through the environment**. The conceptual model will need to consider the mechanisms by which PB-HAPs move through the environment, which include dispersion in the air; deposition (including vapor phase transfer) to soils, surface waters, and plant surfaces; erosion and other runoff phenomena; and uptake and bioconcentration by biota. The physical boundaries of the study area may need to include geographic areas where COPC may be transported after deposition (e.g., PB-HAPs may have the potential to be deposited in a watershed and be carried out of the geographic area defined for the inhalation pathway modeling).

- **The exposure pathways/media of concern**. The potential exposure pathways will include a number of different ingestion pathways and, in some cases, dermal absorption pathways.

- **The human populations potentially receiving exposure**. The potentially exposed populations may need to include persons who do not live within the study area but consume food products that have the potential to become contaminated (e.g., recreational fisher). Additionally, different sensitive sub-populations may be identified (e.g., people who consume large amounts of locally-caught fish because of cultural reasons).

- **The potential adverse health effects (endpoints) that may result from exposure**. The general types of chronic health risks (cancer, non-cancer) may or may not change, depending on the specific COPC being evaluated. However, acute exposures generally are not a concern for multipathway analyses because it would be unlikely for air toxics to accumulate in soil, sediment, or food items to concentrations that would pose, in the absence of a chronic hazard, an acute hazard through the ingestion or dermal pathway.

- **Metrics**. The metrics used to characterize exposure and estimate risk may or may not be different from those used in the inhalation risk assessment. For example, the inhalation assessment may stop at a Tier 1 analysis, while the multipathway assessment may go all the way to a Tier 3 analysis.

15.3 Developing the Multipathway Analysis Plan

As noted in Chapter 6, the analysis plan matches each element of the conceptual model with the analytical approach that the assessor will use to develop data about that element. This section describes the elements of the analysis plan that are unique to the multipathway assessment, including (1) identification of sources; (2) identification of COPC; (3); identification of exposure pathways/routes; (4) identification of exposed populations; and (5) identification of endpoints and metrics.

15.3.1 Identification of the Sources

This part of the analysis plan identifies the sources to be included in the risk assessment. As noted earlier, the focus of multipathway analysis is on sources of the air toxics that persist and which also may bioaccumulate. Within that subset, certain sources may be most important for a specific risk assessment. A tiered approach is recommended for focusing the risk assessment from the initial set of sources to the sources that will drive risk management decisions. The initial tier of analysis generally includes all sources of PB-HAPs. In subsequent tiers of analysis, it may be possible to remove specific sources from the analysis that contribute a very small fraction to the total risk estimate.

15.3.2 Identification of the Chemicals of Potential Concern

This part of the analysis plan identifies the chemicals that will be evaluated in the risk assessment. As noted earlier, the focus of multipathway analysis is on the subset of air toxics that persist and which may also bioaccumulate. Within that subset, certain chemicals may be most important for a specific risk assessment. A tiered approach is recommended for focusing the risk assessment from the initial list of COPC to the set of contaminants that will drive risk management decisions. The initial tier of analysis generally includes all of the air toxics released from the identified important sources. In subsequent tiers of analysis, it may be possible to remove specific chemicals from the analysis if they contribute a very small fraction to the total risk estimate.

15.3.3 Identification of the Exposure Pathways/Routes

This part of the analysis plan identifies the exposure pathways/routes to be evaluated. As noted in Chapter 6, an exposure pathway consists of four elements:

- A source and mechanism of chemical release;
- One or more environmental media (i.e., air, water, soil) in which the chemical is transported from the source;
- A point of potential human contact with the contaminated medium (referred to as the exposure point); and
- An exposure route (e.g., inhalation, ingestion) at the contact or exposure point. The route may be actual or potential, depending on the purpose of the assessment.

The exposure pathway is complete if all four elements can be identified; otherwise the exposure pathway is incomplete and not considered further (see Exhibit 14-2, which presents the potential exposure pathways considered for multipathway assessments).

The exposure points selected for the multipathway risk assessment also will depend on the choice of multipathway assessment approach and may or may not be identical to those used in the inhalation risk assessment. In the example presented in Chapter 11, Mr. McDonald's house was selected as the point of maximum inhalation concentration at a receptor location. The multipathway assessment would likely also evaluate potential exposures via crops, meat, milk, and other foods. However, the focus would be on other exposure points or areas within the farm (e.g., the area where forage fed to dairy cows is grown or where vegetable crops are planted), not on the farmer's house.

15.3.3.1 Characteristics of the Assessment Area

The physical setting is important both in developing the study-specific conceptual model and selecting and providing input parameters for the appropriate multimedia models. As described earlier, the physical setting includes information such as urban vs. rural setting, simple vs. complex terrain, climate and meteorology, and other important geographic features (see Chapter 6). The most important additional information required for multipathway analyses is information on land use, soils, and surface water bodies within the assessment area.[a] Many of the general physical characteristics of the setting will influence the scope of multimedia modeling required. For example, if the sources being evaluated are located in heavily industrialized area, there may be few, if any, agricultural areas or water bodies close enough to receive significant deposition. In this example, deposition to soils in nearby residential areas and subsequent exposure pathways may be the most significant exposure pathways to examine.

- **Land use**. Information on land use is an important part of the physical characteristics of the assessment area discussed in Chapter 6. For multipathway analyses, it is important to identify specific types of land uses that may lead to exposures via ingestion pathways, especially agriculture, fishing, recreation, and residential (indoor and outdoor, including gardening), as well as the location of particular areas where exposures via soil may be of concern (e.g., playgrounds, schools, day care centers). Sources for land use data are discussed in Chapter 6.

- **Soils**. The type and characteristics of soils (e.g., sandy, organic, acidic, alkaline) in the assessment area affects physical phenomena such as soil erosion rates, the types and density of plants supported by the soils, and the physical and chemical characteristics that govern contaminant fate and transport. For example, the bioavailability of a compound may depend partially on soil pH. The specific information needed will depend in part on the input requirements of the multimedia fate and transport models selected for the analysis (see Chapter 19).[b]

- **Water bodies and their associated watersheds**. Water bodies and their associated watersheds are important factors in evaluating some of the major exposure pathways/routes considered in multipathway analyses. For example, the identification of surface water bodies at locations in the assessment area receiving deposition from emission sources indicates the potential for exposures to contaminants from ingestion of fish, and possibly drinking water (drinking water is usually evaluated only if the local population obtains drinking water from

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[a]Maps, aerial photos, and tools such as Geographic Information Systems (GIS) can be very helpful tools for characterizing the exposure setting (see Part VI of this Reference Manual).

[b]Sources of this information may include any existing site descriptions, preliminary risk assessments, county soil surveys, wetlands maps, aerial photographs, U.S. Geological Survey topographic maps, U.S. Department of Agriculture Soil Conservation Service reports, and information from state natural resources agencies.

surface water sources).[c] Information on fishing activity will also be useful in characterizing the potentially exposed population.

Land use and human activities should be characterized in much the same way as Chapter 6 described, except that a broader range of activities/uses needs to be considered. It is important to identify all activities within the assessment area that could result in exposure to contaminants via non-inhalation pathways. These would include hunting, fishing, growing crops (e.g., commercially, as animal feed, or for private consumption), and incidental ingestion of soils. As noted earlier, the multipathway assessment may need to specifically address special populations that are located in impacted areas because of unique characteristics of the exposure setting or to address particular community concerns. For example, a day care center or traditional Tribal fishing/hunting area may be located in an area that is impacted by releases from a facility or source area. Consequently, due to the site-specific exposure characteristics, exposure to children at the day care center or tribal members may need to be addressed, because they may be especially sensitive to the adverse effects and/or the exposure setting may be particularly conducive to exposure. EPA has developed a policy focused on consistently and explicitly evaluating environmental health risks to infants and children in all risk assessments.[1]

15.3.3.2 Scale of the Assessment Area

For inhalation assessments, the study area generally is limited to a 50-km radius from the emissions sources (based on the dispersion models being used). The study area for the multipathway risk assessment generally will be limited similarly to the area in which deposition is modeled. However, certain potential exposure scenarios may require expansion of the study area beyond the modeled deposition area. Examples include:

- The watershed for a lake or pond is within the modeled deposition area, but the lake or pond (where contaminants may accumulate) is outside the deposition area.

- A commercial farm is within the deposition area, and a portion of the crops are consumed by persons living outside the deposition area.

- A popular fishing area is located within the deposition area, and people from outside the deposition area come there to fish.

15.3.3.3 Use of Modeling vs. Monitoring

As this document has previously noted, risk assessors can base estimates of current exposure concentrations on either actual

Multimedia Assessments: Modeling vs. Monitoring

Most multimedia air toxics risk assessments will develop estimates of exposure concentration for non-inhalation pathways primarily through modeling. In some instances, analysts may use monitoring to evaluate the model. In more rare instances, however, analysts will use monitoring to develop exposure concentrations.

[c] Use, area, and location of water bodies and their associated watersheds can typically be identified by reviewing the same land-use land classification maps, topographic maps, and aerial photographs used in identification of land use discussed in Part II of this Reference Manual. Additional information on water body use can also be obtained through discussions with local authorities (e.g., state environmental agencies, fish and wildlife agencies, or local water control districts) about viability to support fish populations and drinking water sources, or current postings of fish advisories.

measurements (i.e., monitoring data) or modeling (in this case, multimedia models). In many cases, monitoring can be helpful in reducing uncertainties in the exposure assessment, because multimedia modeling is more complex and involves more uncertainties. Note, however, that the scope of potential monitoring for multipathway analysis is considerably greater than that for inhalation analyses. A wide range of types of sampling and analysis could be conducted, including sampling of soils, surface waters, sediments, and biota (human food items). Each type of sample has its own methods, protocols, and QA/QC requirements (see Chapter 19). Multimedia sampling and analysis may require additional expertise and effort. The analysis plan, including the quality assurance protection plan (QAPP), will need to be modified accordingly.

15.3.3.4 Quantitation of Exposure

In contrast to the 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. The fundamental equation for dietary intake and ingestion pathways in general is given as:

$$I = \frac{EC \times CR}{BW} \times \frac{EF \times ED}{AT} \qquad \text{(Equation 15-1)}$$

where

I	=	Chemical intake rate, expressed in units of mg/kg-day. For evaluating exposure to non-carcinogens, the intake is referred to as average daily dose (*ADD*); for evaluating exposure to carcinogenic compounds, the intake is referred to as lifetime average daily dose (*LADD*).
EC	=	Exposure concentration of the chemical in the medium of concern for the time period being analyzed, expressed in units of mg/kg for soil and food or mg/L for surface water or beverages (including milk).
CR	=	Consumption rate, the amount of contaminated medium consumed per unit of time, event, or other measure. (e.g., kg/day for soil and food; L/day for water).
EF	=	Exposure frequency (number of days exposed per year).
ED	=	Exposure duration (number of years exposed).
BW	=	Average body weight of the receptor over the exposure period (kg).
AT	=	Averaging time, the period over which exposure is averaged (days). For carcinogens, the averaging time is usually 25,550 days, based on an assumed lifetime exposure of 70 years; for non-carcinogens, averaging time equals *ED* (years) multiplied by 365 days per year.

As noted above, modeling and/or monitoring (sampling and analysis) can be used to determine the exposure concentration (EC) at specified exposure points. However, a variety of approaches and assumptions can be used to determine the remaining variables in the equation, as will be discussed in subsequent chapters. For example, calculation of the intake rate requires assumptions about diet (i.e., how much the exposed individual eats and drinks each day) and body weight (how much the individual weighs). Dietary assumptions need to be specific to the type of food consumed (e.g., fish, milk, beef).

As noted in Section 6.3.3.4, the exposure duration (ED) used to calculate chemical intake rate (I) will have an impact on the choice of toxicity values (e.g., acute vs. chronic) used to characterize risk and hazard. As a general rule, the ED values should match the exposure assumptions used in developing the dose-response values.

15.3.3.5 Evaluation of Uncertainty

As with the inhalation assessment, the evaluation of uncertainty includes both a **summary** of the values used to estimate exposure, including their range, midpoint,and other values; and a qualitative or quantitative **discussion** that evaluates which variables or assumptions have the greatest potential to affect the overall uncertainty in the exposure assessment.

15.3.3.6 Preparation of the Documentation

The analysis plan needs to specify the approach used to document the multipathway exposure assessment, as discussed in Chapter 20.

15.3.4 Identification of the Exposed Population

This part of the analysis plan identifies the exposed population that will be evaluated in the risk assessment. The procedure for characterizing the potentially exposed population generally will be similar to that described for the inhalation pathway (Chapter 6). As noted previously, it may be necessary to include individuals who live outside the modeled deposition area. The manner in which potentially exposed populations are characterized depends on the general approach used for the multipathway assessment (see Section 15.4 below).

15.3.5 Identification of Endpoints and Metrics

This part of the analysis plan identifies the specific human health endpoints that will be evaluated in the risk assessment and the metrics used to quantify exposure and risk. The multimedia assessment uses the same general endpoints (i.e., cancer and non-cancer) and presents the central tendency and high-end tendency descriptors required as the range of risk estimates of the distribution. Risk characterization is discussed in more detail in Chapter 22.

15.4 Exposure Assessment Approach

A variety of approaches are available for multipathway exposure assessments. This section describes two representative approaches that range from a relatively simple approach based on scenarios to a very complex and data-driven approach based on mass-balance models. This discussion is intended to illustrate some of the potential approaches available for multipathway exposure assessment. A given risk assessment might incorporate features of either of the two approaches outlined below, or might feature a different approach.

Regardless of the specific approach taken, EPA recommends a tiered approach to multipathway exposure assessment, in which the exposure assessment moves from relatively simple to more complex as warranted by the quality of available information and its ability to be used to support the risk management decision(s). Chapter 3 provides an overview of tiered approaches to risk assessment.

Childhood exposures need to be considered explicitly in any non-inhalation scenario. This can be done with a separate scenario (e.g., a "resident child") or by incorporating changes in consumption rates, dietary preferences, and body weight with age in the exposure factors incorporated into the scenario. EPA's Risk Assessment Forum recently published guidance on selecting appropriate age groups for assessing childhood exposures.[2]

15.4.1 Scenario Approach

Multipathway exposures may be evaluated by developing a number of scenarios that describe the potential human exposures that might occur via each of the potential exposure pathways identified in the conceptual model. An **exposure scenario** is a combination of exposure pathways by which a single defined human receptor might be exposed to air toxics that persist and which also may bioaccumulate. The specific exposure scenarios defined for a given risk assessment would be based on the characteristics of the exposure setting, potential exposure pathways, potential exposure points or areas, and predominant land uses and activities associated with the potentially exposed population. For example, if the study area included a small lake where fishing might occur, the assessment might include a "fisher" scenario that included ingestion of fish caught in the lake.

The scenario approach generally involves relatively simple modeling and fewer data requirements as modeling inputs. This can be performed by using "linked modeling systems" which can either be relatively simple or incorporate highly sophisticated single-medium models into a single multimedia system. However, these types of models do not assure conservation of mass and therefore may under- or over-estimate exposure concentrations for particular scenarios. The general scenario approach involves:

- Identifying the potential exposure pathways that may be important, including the areas where contaminants have the potential to accumulate in soils, surface waters, sediments, and biota; and specific activities that may result in ingestion of these contaminants (either via incidental ingestion of soil while in the contaminated areas or by consuming the contaminated plants, animals, or surface water).

- Developing a set of scenarios that describe reasonable sets of potential exposure pathways, given the types of people and activities that occur within the study area. The scenarios would include specific exposure factors (e.g., body weight, fish consumption) based on the particular activities identified above. The exposure scenarios should consider children, either as a separate scenarios (e.g., a "resident child") or as part of an overall scenario (e.g., someone who is born in the exposure area and lives there for 30 years, and thus experiences exposure both during childhood and as an adult). The exposure factors could be set initially at conservative levels for screening-level assessments and then at more site-specific levels for higher tiers of analysis. Each exposure scenario also should appropriately consider study-specific sub-populations that may experience different exposure conditions (e.g., because they eat different foods or parts of foods at different rates than the general population).

- Using relatively simple multimedia modeling techniques (e.g., "linked modeling systems" described in Chapter 18) to estimate exposure concentrations in the media and biota of interest to each scenario. Monitoring (sampling or analysis) could be used to augment the modeling effort. For screening-level analyses, the scenarios can be based on the locations with the highest modeled concentrations or deposition rates. For example, a scenario involving consumption of fish could be based on the same location as a residential scenario. In some cases, it may be appropriate to evaluate an exposure scenario assuming exposure through ingestion of fish from one water body and drinking water from a different water body. Such assumptions may need to be refined in subsequent modeling tiers.

- Quantifying the dietary intake for each scenario based on the modeled or estimated exposure concentrations and the specific exposure factors for each scenario.

Several exposure scenarios are commonly used in multipathway risk assessments (Exhibit 15-4). A recent description of several scenarios is provided in EPA's risk assessment guidance for hazardous waste incinerators.[3] In addition to the commonly assessed scenarios provided in Exhibit 15-4, other scenarios may be appropriate, depending on study-specific conditions. For example, if a contaminated surface water body is used for bathing and swimming, incidental ingestion, and dermal exposure from these activities may need to be considered. As another example, the resuspension of contaminated soils (i.e., windblown dust) may be important in some study areas. Note also that exposure of an infant to chlorinated dioxins/furans (and other lipophilic contaminants) via the ingestion of breast milk may be evaluated as an additional exposure pathway, separately from adult exposures, in each of the scenarios outlined below. ***Note also that in each of these scenarios, the risk assessment needs to look at both an adult and child (for example, the "farmer" includes both an adult farmer and a farmer child)***.

Farmer. The farmer scenario is commonly evaluated to account for the combination of exposure pathways to which a person may be exposed in a farm or ranch exposure setting. As indicated in Exhibit 15-4, the farmer is commonly assumed to be exposed to air toxics through one or more of the following exposure pathways:

- Direct inhalation of vapors and particles;
- Incidental ingestion of soil;
- Ingestion of drinking water from surface water sources;
- Ingestion of homegrown produce;
- Ingestion of homegrown beef;
- Ingestion of dairy products from homegrown livestock;
- Ingestion of homegrown chicken;
- Ingestion of eggs from homegrown chickens;
- Ingestion of homegrown pork; and
- Ingestion of breast milk (evaluated separately for an infant [for PCBs, dioxins, and furans]).

In a Tier 1 assessment, the farmer commonly is assumed to consume a certain amount daily (e.g., grams/day) of each food group (beef, pork, poultry, eggs, and milk) to make up a total consumption rate, and amounts consumed are assumed to be homegrown. If site-specific information is available that demonstrates that a farmer does not raise beef, poultry, or pork, and that raising any of these livestock would not occur for a reasonable potential future farmer at a location, then elimination of one or more of these exposure pathways could be justified. The farmer scenario often does not include the fish ingestion exposure pathway. However, in some areas of the country, it is common for farms to also have stock ponds which are fished on a regular basis for the farmer's consumption. Also, ingestion rates (e.g., food, incidental soil ingestion) often are age-dependent.

Exhibit 15-4. Common Exposure Scenarios Used in Multipathway Exposure Assessments				
Exposure Pathways	Scenarios[a]			
	Farm Resident	Resident	Resident with Garden	Local Fish Consumers
Inhalation of Vapors and Particulates[b]	•	•	•	•
Incidental Ingestion of Soil	•	•	•	•
Ingestion of Drinking Water from Surface Water Sources	•	•	•	•
Ingestion of Homegrown Produce	•	–	•	•
Ingestion of Homegrown Beef	•	–	–	–
Ingestion of Milk from Homegrown Cows	•	–	–	–
Ingestion of Homegrown Chicken	•	–	–	–
Ingestion of Eggs from Homegrown Chickens	•	d	d	d
Ingestion of Homegrown Pork	•	–	–	–
Ingestion of Fish	d	d	d	•
Ingestion of Breast Milk	c	c	–	c

Notes:
- • Pathway is included in exposure scenario.
- – Pathway is not included in exposure scenario.
- [a] Exposure scenarios are defined as a combination of exposure pathways evaluated for a receptor at a specific exposure scenario location. Note that these scenarios are not exhaustive (i.e., additional or other scenarios may be relevant to a particular exposure assessment). Note also that within each scenario, the quantitative exposure estimates will vary across age groups.
- [b] Note that inhalation is included in the overall exposure assessment, but the inhalation exposure assessment is performed separately (as described in Part II of this Reference Library).
- [c] Infant exposure to dioxins and/or furans via the ingestion of their mother's breast milk is evaluated for infants as an additional, separate exposure pathway.
- [d] Regional specific exposure setting characteristics (e.g., presence of ponds on farms or within semi-rural residential areas, presence of livestock within semi-rural residential areas) may warrant inclusion of this exposure pathway when evaluating a recommended exposure scenario.

Resident. The resident scenario is commonly evaluated to account for the combination of exposure pathways to which a person may be exposed in an urban or rural (non-farm) setting. As indicated in Exhibit 15-4, the resident is commonly assumed to be exposed to air toxics through the following exposure pathways:

- Direct inhalation of vapors and particles;
- Incidental ingestion of soil;
- Ingestion of drinking water from treated surface water sources; and
- Ingestion of breast milk (evaluated separately for an infant [for PCBs, dioxins, and furans]).

The resident scenario often does not include the fish ingestion exposure pathway. However, in some areas of the country, ponds within semi-rural residential areas support fish for human consumption.

Resident with Garden. The resident with garden scenario is commonly evaluated to account for people who may be exposed while gardening or through the consumption of produce grown in their garden in an urban or rural (non-farm) setting. As indicated in Exhibit 15-4, the resident with garden is commonly assumed to be exposed to air toxics through the same exposure pathways as the resident scenario, with one additional exposure pathway:

- Ingestion of homegrown produce.

Local Fish Consumer. The local fish consumer scenario is evaluated to account for the combination of exposure pathways to which a receptor may be exposed in an urban or rural setting where fish is the main component of the person's diet. As indicated in Exhibit 15-4, the local fish consumer is commonly assumed to be exposed to air toxics through the following exposure pathways:

- Direct inhalation of vapors and particles;
- Incidental ingestion of soil;
- Ingestion of drinking water from surface water sources;
- Ingestion of homegrown produce;
- Ingestion of fish; and
- Ingestion of breast milk (evaluated separately for an infant [for PCBs, dioxins, and furans]).

In many cases, local fish consumers are assumed to grow some of their own produce, but this may or may not be relevant to a particular risk assessment. Also note that in some parts of the country, a primary reliance on fishing as a source or dietary protein is common - a circumstance known as "subsistence fishing." Subsistence hunting may also be important for some groups.

15.4.2 Population-Based Approach

Multipathway exposures may be evaluated by tracking individual members of a population and their inhalation and ingestion through time and space. Such analyses may incorporate a user-specified number of **simulated individuals** or population groups (**cohorts**) to represent the population in the study area. A cohort is defined here as a group of people within a population with the same demographic variables who are assumed to have similar exposures. In this approach, the exposure analysis process consists of relating chemical concentrations in environmental media (e.g., air, soil, water) to chemical concentrations in the exposure media with which a person or population has contact (e.g., soil, food, household dust). Exposure is estimated by tracking the movement of a population cohort through locations where chemical exposure can occur according to a specific activity pattern.[4] Models such as the Stochastic Human Exposure and Dose Simulation Model (SHEDS), Calendex, the Hazardous Air Pollution Exposure Model (HAPEM), and the Total Risk Integrated Methodology, Exposure Event Model (TRIM.Expo) incorporate this approach (see Chapter 19). The general approach, which is analogous to the inhalation exposure modeling techniques described in Chapter 9, involves:

- Defining **exposure districts** – geographic locations within the study area where there is potential contact between humans and a pollutant – and estimating chemical concentrations within each exposure district (through modeling and/or measurement).

- Preparing inventories of chemical concentrations in each microenvironment in each exposure district at selected time intervals (e.g., days, hours). These inventories may be developed using mass-balance approaches that predict the partitioning of chemicals throughout the environment or through the use of microenvironment factors.

- Identifying the characteristics and activity patterns of each population cohort or set of representative individuals (e.g., the demographic characteristics of the individual; the locations where the individual lives, works, etc.; the amount of time spent in each location, and the individual's activities within a location). These activity patterns should be representative of the exposed population of concern. For representative individuals or cohorts, each simulated person/cohort is represented by a "personal profile" or "activity pattern" developed by selecting from a set of variables that include:

  – Demographic variables (e.g. age, sex), which are generated based on census data;
  – Residential variables (e.g., where the person lives, works, etc., which are generated based on sets of distribution data;
  – Daily varying variables (e.g., how long a person works in a garden), which are generated based on distribution data that change daily during the simulation period;
  – Physiological variables (e.g., height, weight), which are generated based on age group-specific distribution data; and
  – Dietary variables (e.g., amount and type of food consumed), which are generated based on sets of distribution data.

  Profiles or activity patterns may be developed using probability density functions, allowing the analysis to incorporate probabilistic techniques such as Monte Carlo analysis (see Part VII of this reference manual).

- Summing the exposures for each exposure event over the assumed duration of exposure (e.g., lifetime or portion of a lifetime).

The primary advantage of the population-based approach is that it is a more realistic exposure assessment that simulates how people actually live and work within the study area. It therefore can provide a more complete characterization of the spatial and temporal patterns of exposure. The primary disadvantage of the cohort approach is the time and resources it requires, including significant input data requirements.

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