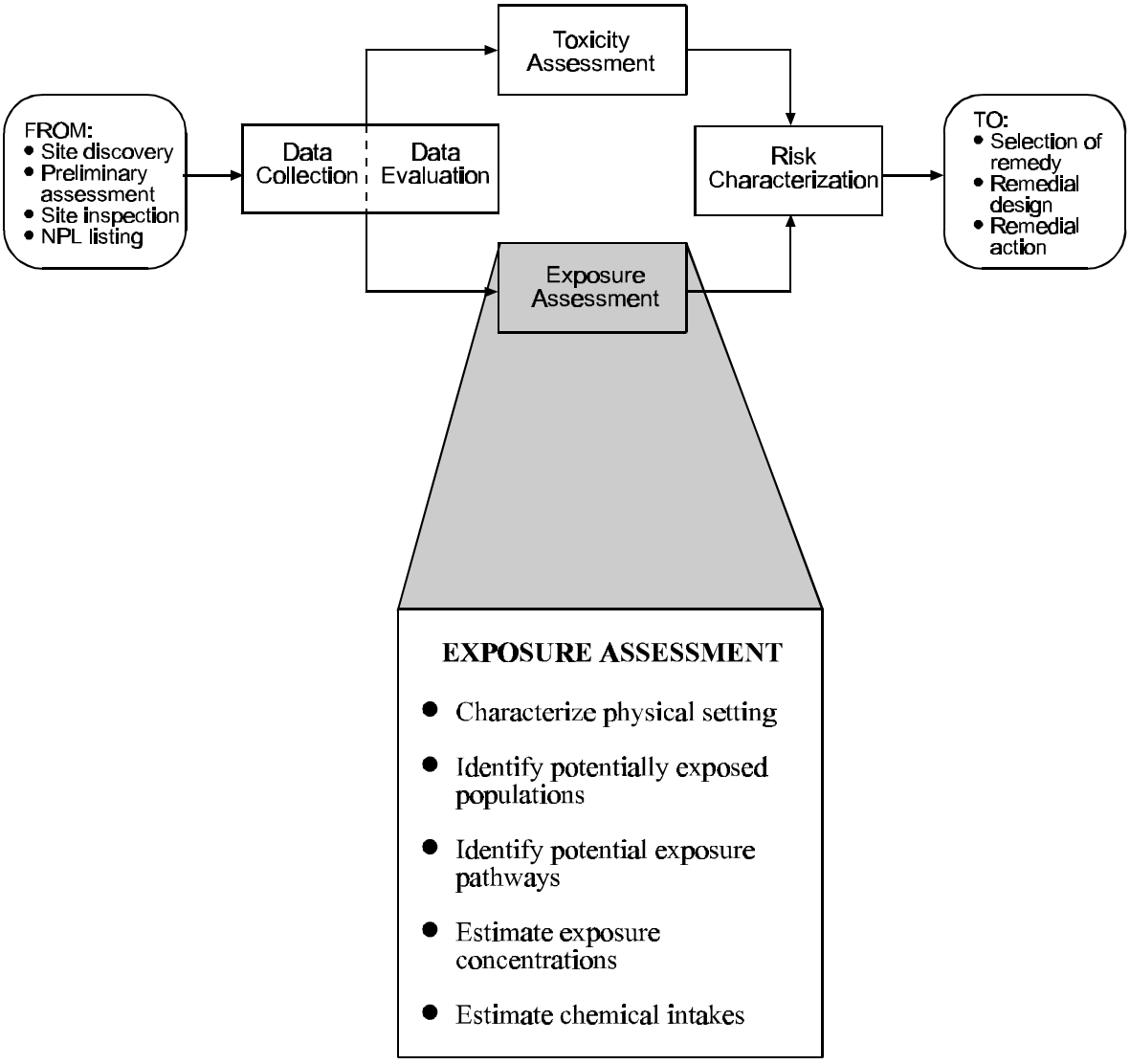
CHAPTER 6
EXPOSURE ASSESSMENT



CHAPTER 6

EXPOSURE ASSESSMENT

This chapter describes the procedures for conducting an exposure assessment as part of the baseline risk assessment process at Superfund sites. The objective of the exposure assessment is to estimate the type and magnitude of exposures to the chemicals of potential concern that are present at or migrating from a site. The results of the exposure assessment are combined with chemical-specific toxicity information to characterize potential risks.

The procedures and information presented in this chapter represent some new approaches to exposure assessment as well as a synthesis of currently available exposure assessment guidance and information published by EPA. Throughout this chapter, relevant exposure assessment documents are referenced as sources of more detailed information supporting the exposure assessment process.

6.1 BACKGROUND

Exposure is defined as the contact of an organism (humans in the case of health risk assessment) with a chemical or physical agent (EPA 1988a). The magnitude of exposure is determined by measuring or estimating the amount of an agent available at the exchange boundaries (i.e., the lungs, gut, skin) during a specified time period. Exposure assessment is the determination or estimation (qualitative or quantitative) of the magnitude, frequency, duration, and route of exposure. Exposure assessments may consider past, present, and future exposures, using varying assessment techniques for each phase. Estimates of current exposures can be based on measurements or models of existing conditions, those of future exposures can be based on models of future conditions, and those of past exposures can be based on measured or modeled past concentrations or measured chemical concentrations in tissues. Generally, Superfund exposure assessments are concerned with current and future exposures. If human monitoring is planned to assess current or past exposures, the Agency for Toxic Substances and Disease Registry (ATSDR) should be consulted to take the lead in conducting these studies and in assessing the current health status of the people near the site based on the monitoring results.

6.1.1 COMPONENTS OF AN EXPOSURE ASSESSMENT

The general procedure for conducting an exposure assessment is illustrated in Exhibit 6-1. This procedure is based on EPA's published *Guidelines for Exposure Assessment* (EPA 1986a) and on other related guidance (EPA 1988a, 1988b). It is an adaptation of the generalized exposure assessment process to the particular needs of Superfund site risk assessments. Although some exposure assessment activities may have been started earlier (e.g., during RI/FS scoping or even before the RI/FS process began), the detailed exposure assessment process begins after the chemical data have been collected and validated and the chemicals of potential concern have been selected (see Chapter 5, Section 5.3.3). The exposure assessment proceeds with the following steps.

ACRONYMS FOR CHAPTER 6

ATSDR = Agency for Toxic Substances and Disease Registry
BCF = Bioconcentration Factor
CDI = Chronic Daily Intake
CEAM = Center for Exposure Assessment Modeling
NOAA = National Oceanographic and Atmospheric Administration
NTGS = National Technical Guidance Studies
OAQPS = Office of Air Quality Planning and Standards
RME = Reasonable Maximum Exposure
SDI = Subchronic Daily Intake
SEAM = Superfund Exposure Assessment Manual
USGS = U.S. Geological Survey

DEFINITIONS FOR CHAPTER 6

Absorbed Dose. The amount of a substance penetrating the exchange boundaries of an organism after contact. Absorbed dose is calculated from the intake and the absorption efficiency. It usually is expressed as mass of a substance absorbed into the body per unit body weight per unit time (e.g., mg/kg-day).

Administered Dose. The mass of a substance given to an organism and in contact with an exchange boundary (e.g., gastrointestinal tract) per unit body weight per unit time (e.g., mg/kg-day).

Applied Dose. The amount of a substance given to an organism, especially through dermal contact.

Chronic Daily Intake (CDI). Exposure expressed as mass of a substance contacted per unit body weight per unit time, averaged over a long period of time (as a Superfund program guideline, seven years to a lifetime).

Contact Rate. Amount of medium (e.g., ground water, soil) contacted per unit time or event (e.g. liters of water ingested per day).

Exposure. Contact of an organism with a chemical or physical agent. Exposure is quantified as the amount of the agent available at the exchange boundaries of the organism (e.g., skin, lungs, gut) and available for absorption.

Exposure Assessment. The determination or estimation (qualitative or quantitative) of the magnitude, frequency, duration, and route of exposure.

Exposure Event. An incident of contact with a chemical or physical agent. An exposure event can be defined by time (e.g., day, hour) or by the incident (e.g., eating a single meal of contaminated fish).

Exposure Pathway. The course a chemical or physical agent takes from a source to an exposed organism. An exposure pathway describes a unique mechanism by which an individual or population is exposed to chemicals or physical agents at or originating from a site. Each exposure pathway includes a source or release from a source, an exposure point, and an exposure route. If the exposure point differs from the source, a transport/exposure medium (e.g., air) or media (in cases of intermedia transfer) also is included.

Exposure Point. A location of potential contact between an organism and a chemical or physical agent.

Exposure Route. The way a chemical or physical agent comes in contact with an organism (e.g., by ingestion, inhalation, dermal contact).

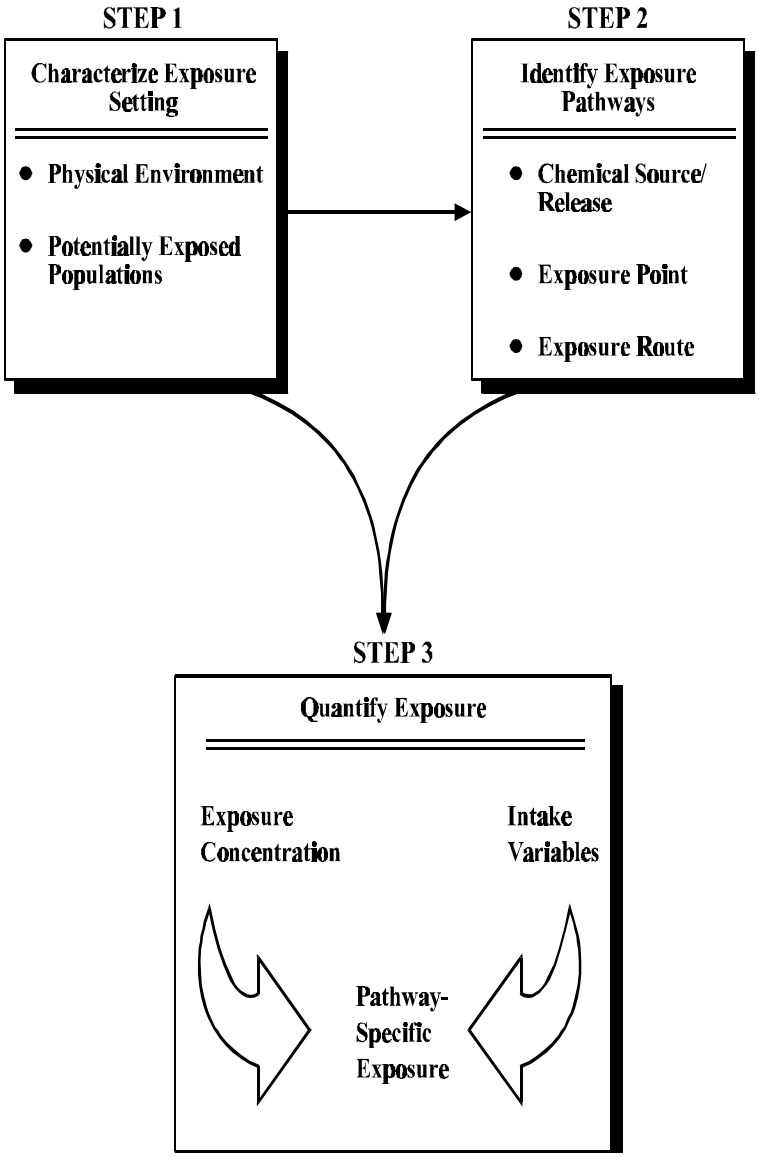
Intake. A measure of exposure expressed as the mass of a substance in contact with the exchange boundary per unit body weight per unit time (e.g., mg chemical/kg body weight-day). Also termed the normalized exposure rate equivalent to administered dose.

Lifetime Average Daily Intake. Exposure expressed as mass of a substance contacted per unit body weight per unit time, averaged over a lifetime.

Subchronic Daily Intake (SDI). Exposure expressed as mass of a substance contacted per unit body weight per unit time, averaged over a portion of a lifetime (as a Superfund program guideline, two weeks to seven years).

Step 1 -- Characterization of exposure setting (Section 6.2). In this step, the assessor characterizes the exposure setting with respect to the general physical characteristics of the site and the characteristics of the populations on and near the site. Basic site characteristics such as climate, vegetation, ground-water hydrology, and the presence and location of surface water are identified in this step. Populations also are identified and are described with respect to those characteristics that influence exposure, such as location relative to the site, activity patterns, and the presence of sensitive subpopulations. This step considers the characteristics of the current population, as well as those of any potential future populations that may differ under an alternate land use.

EXHIBIT 6-1
THE EXPOSURE ASSESSMENT PROCESS



Step 2 -- Identification of exposure pathways (Section 6.3). In this step, the exposure assessor identifies those pathways by which the previously identified populations may be exposed. Each exposure pathway describes a unique mechanism by which a population may be exposed to the chemicals at or originating from the site. Exposure pathways are identified based on consideration of the sources, releases, types, and locations of chemicals at the site; the likely environmental fate (including persistence, partitioning, transport, and intermedia transfer) of these chemicals; and the location and activities of the potentially exposed populations. Exposure points (points of potential contact with the chemical) and routes of exposure (e.g., ingestion, inhalation) are identified for each exposure pathway.

Step 3 -- Quantification of exposure (Section 6.4). In this step, the assessor quantifies the magnitude, frequency and duration of exposure for each pathway identified in Step 2. This step is most often conducted in two stages: estimation of exposure concentrations and calculation of intakes.

Estimation of exposure concentrations (Section 6.5). In this part of step 3, the exposure assessor determines the concentration of chemicals that will be contacted over the exposure period. Exposure concentrations are estimated using monitoring data and/or chemical transport and environmental fate models. Modeling may be used to estimate future chemical concentrations in media that are currently contaminated or that may become contaminated, and current concentrations in media and/or at locations for which there are no monitoring data.

Calculation of intakes (Section 6.6). In this part of step 3, the exposure assessor calculates chemical-specific exposures for each exposure pathway identified in Step 2. Exposure estimates are expressed in terms of the mass of substance in contact with the body per unit body weight per unit time (e.g., mg chemical per kg body weight per day, also expressed as mg/kg-day). These exposure estimates are termed "intakes" (for the purposes of this manual) and represent the normalized exposure rate. Several terms common in other EPA documents and the literature are equivalent or related to intake (see box on this page and definitions box on page 6-2). Chemical intakes are calculated using equations that include variables for exposure concentration, contact rate, exposure frequency, exposure duration, body weight, and exposure averaging time. The values of some of these variables depend on site conditions and the characteristics of the potentially exposed population.

After intakes have been estimated, they are organized by population, as appropriate (Section 6.7). Then, the sources of uncertainty (e.g., variability in analytical data, modeling results, parameter assumptions) and their effect on the exposure estimates are evaluated and summarized (Section 6.8). This information on uncertainty is important to site decision-makers who must evaluate the results of the exposure and risk assessment and make decisions regarding the degree of remediation required at a site. The exposure assessment concludes with a summary of the estimated intakes for each pathway evaluated (Section 6.9).

TERMS EQUIVALENT OR RELATED TO INTAKE

Normalized Exposure Rate. Equivalent to intake

Administered Dose. Equivalent to intake

Applied Dose. Equivalent to intake

Absorbed Dose. Equivalent to intake multiplied by an absorption factor

6.1.2 REASONABLE MAXIMUM EXPOSURE

Actions at Superfund sites should be based on an estimate of the reasonable maximum exposure (RME) expected to occur under both current and future land-use conditions. The reasonable maximum exposure is defined here as the highest exposure that is reasonably expected to occur at a site. RMEs are estimated for individual pathways. If a population is exposed via more than one pathway, the combination of exposures across pathways also must represent an RME.

Estimates of the reasonable maximum exposure necessarily involve the use of professional judgment. This chapter provides guidance for determining the RME at a site and identifies some exposure variable values appropriate for use in this determination. The specific values identified should be regarded as general recommendations, and could change based on site-specific information and the particular needs of the EPA remedial project manager (RPM). Therefore, these recommendations should be used in conjunction with input from the RPM responsible for the site.

In the past, exposures generally were estimated for an average and an upper-bound exposure case, instead of a single exposure case (for both current and future land use) as recommended here. The advantage of the two case approach is that the resulting range of exposures provides some measure of the uncertainty surrounding these estimates. The disadvantage of this approach is that the upper-bound estimate of exposure may be above the range of possible exposures, whereas the average estimate is lower than exposures potentially experienced by much of the population. The intent of the RME is to estimate a conservative exposure case (i.e., well above the average case) that is still within the range of possible exposures. Uncertainty is still evaluated under this approach. However, instead of combining many sources of uncertainty into average and upper-bound exposure estimates, the variation in individual exposure variables is used to evaluate uncertainty (See Section 6.8). In this way, the variables contributing most to uncertainty in the exposure estimate are more easily identified.

6.2 STEP 1: CHARACTERIZATION OF EXPOSURE SETTING

The first step in evaluating exposure at Superfund sites is to characterize the site with respect to its physical characteristics as well as those of the human populations on and near the site. The output of this step is a qualitative evaluation of the site and surrounding populations with respect to those characteristics that influence exposure. All information gathered during this step will support the identification of exposure pathways in Step 2. In addition, the information on the potentially exposed populations will be used in Step 3 to determine the values of some intake variables.

6.2.1 CHARACTERIZE PHYSICAL SETTING

Characterize the exposure setting with respect to the general physical characteristics of the site. Important site characteristics include the following:

- climate (e.g., temperature, precipitation);
- meteorology (e.g., wind speed and direction);
- geologic setting (e.g., location and characterization of underlying strata);
- vegetation (e.g., unvegetated, forested, grassy);
- soil type (e.g., sandy, organic, acid, basic);
- ground-water hydrology (e.g., depth, direction and type of flow); and
- location and description of surface water (e.g., type, flow rates, salinity).

Sources of this information include site descriptions and data from the preliminary assessment (PA), site inspection (SI), and remedial investigation (RI) reports. Other sources include county soil surveys, wetlands maps, aerial photographs, and reports by the National Oceanographic and Atmospheric Association (NOAA) and the U.S. Geological Survey (USGS). The assessor also should consult with appropriate technical experts (e.g., hydrogeologists, air modelers) as needed to characterize the site.

6.2.2 CHARACTERIZE POTENTIALLY EXPOSED POPULATIONS

Characterize the populations on or near the site with respect to location relative to the site, activity patterns, and the presence of sensitive subgroups.

Determine location of current populations relative to the site . Determine the distance and direction of potentially exposed populations from the site. Identify those populations that are closest to or actually living on the site and that, therefore, may have the greatest potential for exposure. Be sure to include potentially exposed distant populations, such as public water supply consumers and distant consumers of fish or shellfish or agricultural products from the site area. Also include populations that could be exposed in the future to chemicals that have migrated from the site. Potential sources of this information include:

- site visit;
- other information gathered as part of the SI or during the initial stages of the RI;
- population surveys conducted near the site;
- topographic, land use, housing or other maps; and
- recreational and commercial fisheries data.

Determine current land use . Characterize the activities and activity patterns of the potentially exposed population. The following land use categories will be applicable most often at Superfund sites:

- residential;
- commercial/industrial; and
- recreational.

Determine the current land use or uses of the site and surrounding area. The best source of this information is a site visit. Look for homes, playgrounds, parks, businesses, industries, or other land uses on or in the vicinity of the site. Other sources on local land use include:

- zoning maps;
- state or local zoning or other land use-related laws and regulations;
- data from the U.S. Bureau of the Census;
- topographic, land use, housing or other maps; and
- aerial photographs.

Some land uses at a site may not fit neatly into one of the three land use categories and other land use classifications may be more appropriate (e.g., agricultural land use). At some sites it may be most appropriate to have more than one land use category.

After defining the land use(s) for a site, identify human activities and activity patterns associated with each land use. This is basically a "common sense" evaluation and is not based on any specific data sources, but rather on a general understanding of what activities occur in residential, business, or recreational areas.

Characterize activity patterns by doing the following.

- Determine the percent of time that the potentially exposed population(s) spend in the potentially contaminated area. For example, if the potentially exposed population is commercial or industrial, a reasonable maximum daily exposure period is likely to be 8 hours (a typical work day). Conversely, if the population is residential, a maximum daily exposure period of 24 hours is possible.
- Determine if activities occur primarily indoors, outdoors, or both. For example, office workers may spend all their time indoors, whereas construction workers may spend all their time outdoors.
- Determine how activities change with the seasons. For example, some outdoor, summertime recreational activities (e.g., swimming, fishing) will occur less frequently or not at all during the winter months. Similarly, children are likely to play outdoors less frequently and with more clothing during the winter months.
- Determine if the site itself may be used by local populations, particularly if access to the site is not restricted or otherwise limited (e.g., by distance). For example, children living in

the area could play onsite, and local residents could hunt or hike onsite.

- Identify any site-specific population characteristics that might influence exposure. For example, if the site is located near major commercial or recreational fisheries or shellfisheries, the potentially exposed population is likely to eat more locally-caught fish and shellfish than populations located inland.

Determine future land use. Determine if any activities associated with a current land use are likely to be different under an alternate future land use. For example, if ground water is not currently used in the area of the site as a source of drinking water but is of potable quality, future use of ground water as drinking water would be possible. Also determine if land use of the site itself could change in the future. For example, if a site is currently classified as industrial, determine if it could possibly be used for residential or recreational purposes in the future.

Because residential land use is most often associated with the greatest exposures, it is generally the most conservative choice to make when deciding what type of alternate land use may occur in the future. However, an assumption of future residential land use may not be justifiable if the probability that the site will support residential use in the future is exceedingly small.

Therefore, determine possible alternate future land uses based on available information and professional judgment. Evaluate pertinent information sources, including (as available):

- master plans (city or county projections of future land use);
- Bureau of the Census projections; and
- established land use trends in the general area and the area immediately surrounding the site (use Census Bureau or state or local reports, or use general historical accounts of the area).

Note that while these sources provide potentially useful information, they should not be interpreted as providing proof that a certain land use will or will not occur.

Assume future residential land use if it seems possible based on the evaluation of the available information. For example, if the site is currently industrial but is located near residential areas in an urban area, future residential land use may be a reasonable possibility. If the site is industrial and is located in a very rural area with a low population density and projected low growth, future residential use would probably be unlikely. In this case, a more likely alternate future land use may be recreational. At some sites, it may be most reasonable to assume that the land use will not change in the future.

There are no hard-and-fast rules by which to determine alternate future land use. The use of professional judgment in this step is critical. Be sure to consult with the RPM about any decision regarding alternate future land use. Support the selection of any alternate land use with a logical, reasonable argument in the exposure assessment chapter of the risk assessment report. Also include a qualitative statement of the likelihood of the future land use occurring.

Identify subpopulations of potential concern. Review information on the site area to determine if any subpopulations may be at increased risk from chemical exposures due to increased sensitivity, behavior patterns that may result in high exposure, and/or current or past exposures from other sources. Subpopulations that may be more sensitive to chemical exposures include infants and children, elderly people, pregnant and nursing women, and people with chronic illnesses. Those potentially at higher risk due to behavior patterns include children, who are more likely to contact soil, and persons who may eat large amounts of locally caught fish or locally grown produce (e.g., home-grown vegetables). Subpopulations at higher risk due to exposures from other sources include individuals exposed to chemicals during occupational activities and individuals living in industrial areas.

To identify subpopulations of potential concern in the site area, determine locations of schools, day care centers, hospitals, nursing homes, retirement communities, residential areas with children, important commercial or recreational fisheries near the site, and major industries potentially involving chemical exposures. Use local census data and information from local public health officials for this determination.

6.3 STEP 2: IDENTIFICATION OF EXPOSURE PATHWAYS

This section describes an approach for identifying potential human exposure pathways at a Superfund site. An exposure pathway describes the course a chemical or physical agent takes from the source to the exposed individual. An exposure pathway analysis links the sources, locations, and types of environmental releases with population locations and activity patterns to determine the significant pathways of human exposure.

An exposure pathway generally consists of four elements: (1) a source and mechanism of chemical release, (2) a retention or transport medium (or media in cases involving media transfer of chemicals), (3) a point of potential human contact with the contaminated medium (referred to as the exposure point), and (4) an exposure route (e.g., ingestion) at the contact point. A medium contaminated as a result of a past release can be a contaminant source for other media (e.g., soil contaminated from a previous spill could be a contaminant source for ground water or surface water). In some cases, the source itself (i.e., a tank, contaminated soil) is the exposure point, without a release to any other medium. In these latter cases, an exposure pathway consists of (1) a source, (2) an exposure point, and (3) an exposure route. Exhibit 6-2 illustrates the basic elements of each type of exposure pathway.

The following sections describe the basic analytical process for identifying exposure pathways at Superfund sites and for selecting pathways for quantitative analysis. The pathway analysis described below is meant to be a qualitative evaluation of pertinent site and chemical information, and not a rigorous quantitative evaluation of factors such as source strength, release rates, and chemical fate and transport. Such factors are considered later in the exposure assessment during the quantitative determination of exposure concentrations (Section 6.5).

6.3.1 IDENTIFY SOURCES AND RECEIVING MEDIA

To determine possible release sources for a site in the absence of remedial action, use all available site descriptions and data from the PA, SI, and RI reports. Identify potential release mechanisms and receiving media for past, current, and future releases. Exhibit 6-3 lists some typical release sources, release mechanisms, and receiving media at Superfund sites. Use monitoring data in conjunction with information on source locations to support the analysis of past, continuing, or threatened releases. For example, soil contamination near an old tank would suggest the tank (source) ruptured or leaked (release mechanism) to the ground (receiving media). Be sure to note any source that could be an exposure point in addition to a release source (e.g., open barrels or tanks, surface waste piles or lagoons, contaminated soil).

Map the suspected source areas and the extent of contamination using the available information and monitoring data. As an aid in evaluating air sources and releases, Volumes I and II of the National Technical Guidance Studies (NTGS; EPA 1989a,b) should be consulted.

EXHIBIT 6-2

ILLUSTRATION OF EXPOSURE PATHWAYS

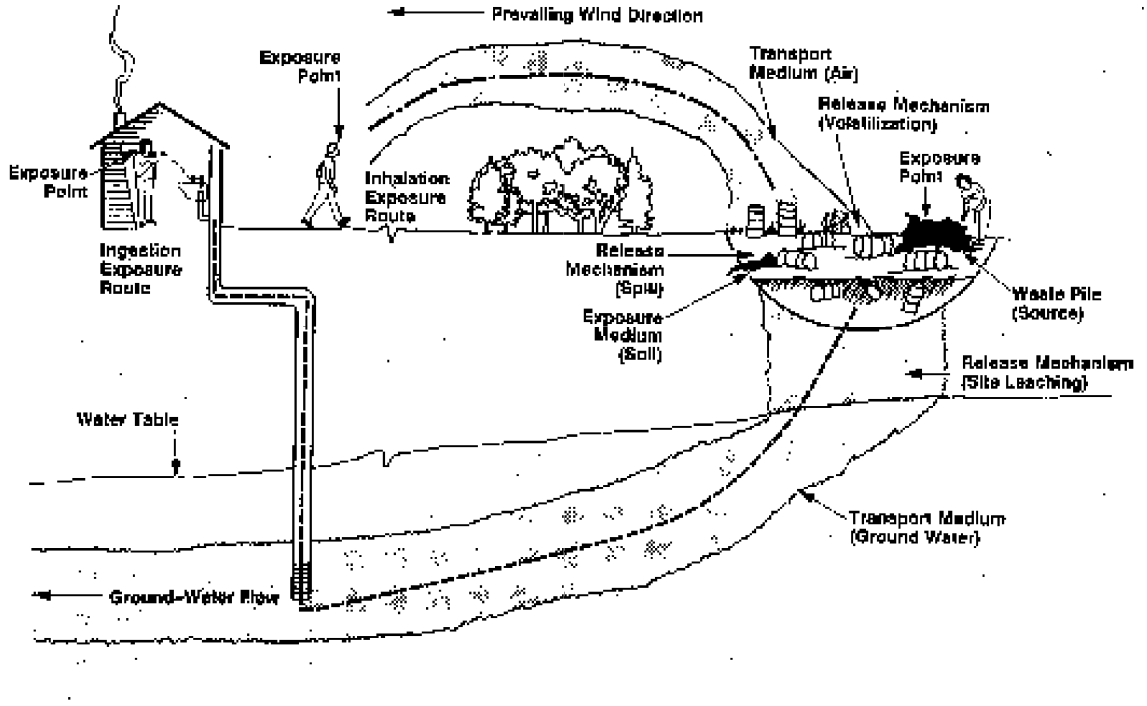


EXHIBIT 6-3

COMMON CHEMICAL RELEASE SOURCES AT SITES IN THE ABSENCE OF REMEDIAL ACTION

Receiving Medium	Release Mechanism	Release Source
Air	Volatilization	Surface wastes -- lagoons, ponds, pits, spills Contaminated surface water Contaminated surface soil Contaminated wetlands Leaking drums
	Fugitive dust generation	Contaminated surface soil Waste piles
Surface water	Surface runoff	Contaminated surface soil
	Episodic overland flow	Lagoon overflow Spills, leaking containers
	Ground-water seepage	Contaminated ground water
Ground water	Leaching	Surface or buried wastes Contaminated soil
Soil	Leaching	Surface or buried wastes
	Surface runoff	Contaminated surface soil
	Episodic overland flow	Lagoon overflow Spills, leaking containers
	Fugitive dust generation/ deposition	Contaminated surface soil Waste piles
	Tracking	Contaminated surface soil
Sediment	Surface runoff, Episodic overland flow	Surface wastes -- lagoons, ponds, pits, spills Contaminated surface soil
	Ground-water seepage	Contaminated ground water
	Leaching	Surface or buried wastes Contaminated soil
Biota	Uptake (direct contact, ingestion, inhalation)	Contaminated soil, surface water, sediment, ground water or air Other biota

6.3.2 EVALUATE FATE AND TRANSPORT IN RELEASE MEDIA

Evaluate the fate and transport of the chemicals to predict future exposures and to help link sources with currently contaminated media. The fate and transport analysis conducted at this stage of the exposure assessment is not meant to result in a quantitative evaluation of media-specific chemical concentrations. Rather, the intent is to identify media that are receiving or may receive site-related chemicals. At this stage, the assessor should answer the questions: What chemicals occur in the sources at the site and in the environment? In what media (onsite and offsite) do they occur now? In what media and at what location may they occur in the future? Screening-level analyses using available data and simplified calculations or analytical models may assist in this qualitative evaluation.

After a chemical is released to the environment it may be:

- transported (e.g., convected downstream in water or on suspended sediment or through the atmosphere);
- physically transformed (e.g., volatilization, precipitation);
- chemically transformed (e.g., photolysis, hydrolysis, oxidation, reduction, etc.);
- biologically transformed (e.g, biodegradation); and/or
- accumulated in one or more media (including the receiving medium).

To determine the fate of the chemicals of potential concern at a particular site, obtain information on their physical/chemical and environmental fate properties. Use computer data bases (e.g., SRC's Environmental Fate, CHEMFATE, and BIODEG data bases; BIOSIS; AQUIRE) and the open literature as necessary as sources for up-to-date information on the physical/chemical and fate properties of the chemicals of potential concern. Exhibit 6-4 lists some important chemical-specific fate parameters and briefly describes how these can be used to evaluate a chemical's environmental fate.

Also consider site-specific characteristics (identified in Section 6.2.1) that may influence fate and transport. For example, soil characteristics such as moisture content, organic carbon content, and cation exchange capacity can greatly influence the movement of many chemicals. A high water table may increase the probability of leaching of chemicals in soil to ground water.

Use all applicable chemical and site-specific information to evaluate transport within and between media and retention or accumulation within a single medium. Use monitoring data to identify media that are contaminated now and the fate pathway analysis to identify media that may be contaminated now (for media not sampled) or in the future. Exhibit 6-5 presents some important questions to consider when developing these pathways. Exhibit 6-6 presents a series of flow charts useful when evaluating the fate and transport of chemicals at a site.

6.3.3 IDENTIFY EXPOSURE POINTS AND EXPOSURE ROUTES

After contaminated or potentially contaminated media have been identified, identify exposure points by determining if and where any of the potentially exposed populations (identified in Step 1) can contact these media. Consider population locations and activity patterns in the area, including those of subgroups that may be of particular concern. Any point of potential contact with a contaminated medium is an exposure point. Try to identify those exposure points where the concentration that will be contacted is the greatest. Therefore, consider including any contaminated media or sources onsite as a potential exposure point if the site is currently used, if access to the site under current conditions is not restricted or otherwise limited (e.g., by distance), or if contact is possible under an alternate future land use. For potential offsite exposures, the highest exposure concentrations often will be at the points closest to and downgradient or downwind of the site. In some cases, highest concentrations may be encountered at points distant from the site. For example, site-related chemicals may be transported and deposited in a distant water body where they may be subsequently bioconcentrated by aquatic organisms.

EXHIBIT 6-4

IMPORTANT PHYSICAL/CHEMICAL AND ENVIRONMENTAL FATE PARAMETERS

K_{oc} provides a measure of the extent of chemical partitioning between organic carbon and water at equilibrium. The higher the K_{oc}, the more likely a chemical is to bind to soil or sediment than to remain in water.

K_d provides a soil or sediment-specific measure of the extent of chemical partitioning between soil or sediment and water, unadjusted for dependence upon organic carbon. To adjust for the fraction of organic carbon present in soil or sediment (f_{oc}), use $K_d = K_{oc} \times f_{oc}$. The higher the K_d, the more likely a chemical is to bind to soil or sediment than to remain in water.

K_{ow} provides a measure of the extent of chemical partitioning between water and octanol at equilibrium. The greater the K_{ow} the more likely a chemical is to partition to octanol than to remain in water. Octanol is used as a surrogate for lipids (fat), and K_{ow} can be used to predict bioconcentration in aquatic organisms.

Solubility is an upper limit on a chemical's dissolved concentration in water at a specified temperature. Aqueous concentrations in excess of solubility may indicate sorption onto sediments, the presence of solubilizing chemicals such as solvents, or the presence of a non-aqueous phase liquid.

Henry's Law Constant provides a measure of the extent of chemical partitioning between air and water at equilibrium. The higher the Henry's Law constant, the more likely a chemical is to volatize than to remain in water.

Vapor Pressure is the pressure exerted by a chemical vapor in equilibrium with its solid or liquid form at any given temperature. It is used to calculate the rate of volatilization of a pure substance from a surface or in estimating a Henry's Law constant for chemicals with low water solubility. The higher the vapor pressure, the more likely a chemical is to exist in a gaseous state.

Diffusivity describes the movement of a molecule in a liquid or gas medium as a result of differences in concentration. It is used to calculate the dispersive component of chemical transport. The higher the diffusivity, the more likely a chemical is to move in response to concentration gradients.

Bioconcentration Factor (BCF) provides a measure of the extent of chemical partitioning at equilibrium between a biological medium such as fish tissue or plant tissue and an external medium such as water. The higher the BCF, the greater the accumulation in living tissue is likely to be.

Media-specific Half-life provides a relative measure of the persistence of a chemical in a given medium, although actual values can vary greatly depending on site-specific conditions. The greater the half-life, the more persistent a chemical is likely to be.

EXHIBIT 6-5

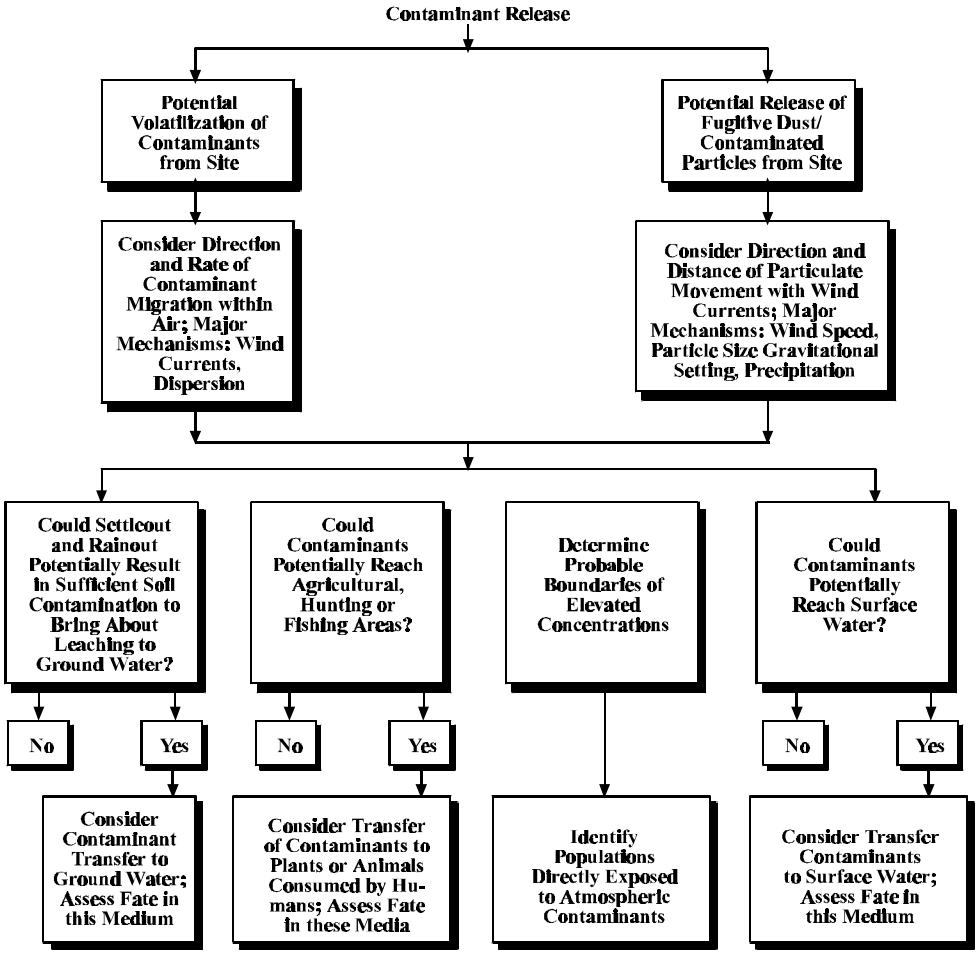
IMPORTANT CONSIDERATIONS FOR DETERMINING THE ENVIRONMENTAL FATE AND TRANSPORT OF THE CHEMICALS OF POTENTIAL CONCERN AT A SUPERFUND SITE

- **What are the principal mechanisms for change or removal in each of the environmental media?**
- **How does the chemical behave in air, water, soil, and biological media? Does it bioaccumulate or biodegrade? Is it absorbed or taken up by plants?**
- **Does the agent react with other compounds in the environment?**
- **Is there intermedia transfer? What are the mechanisms for intermedia transfer? What are the rates of the intermedia transfer or reaction mechanism?**
- **How long might the chemical remain in each environmental medium? How does its concentration change with time in each medium?**
- **What are the products into which the agent might degrade or change in the environment? Are these products potentially of concern?**
- **Is a steady-state concentration distribution in the environment or in specific segments of the environment achieved?**

EXHIBIT 6-6

FLOW CHART FOR FATE AND TRANSPORT ASSESSMENTS

Environmental fate and transport assessment: atmosphere



Source: Adapted from EPA 1988b

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EXHIBIT 6–6 (continued)

FLOW CHART FOR FATE AND TRANSPORT ASSESSMENTS

Environmental fate and transport assessment: surface water and sediment

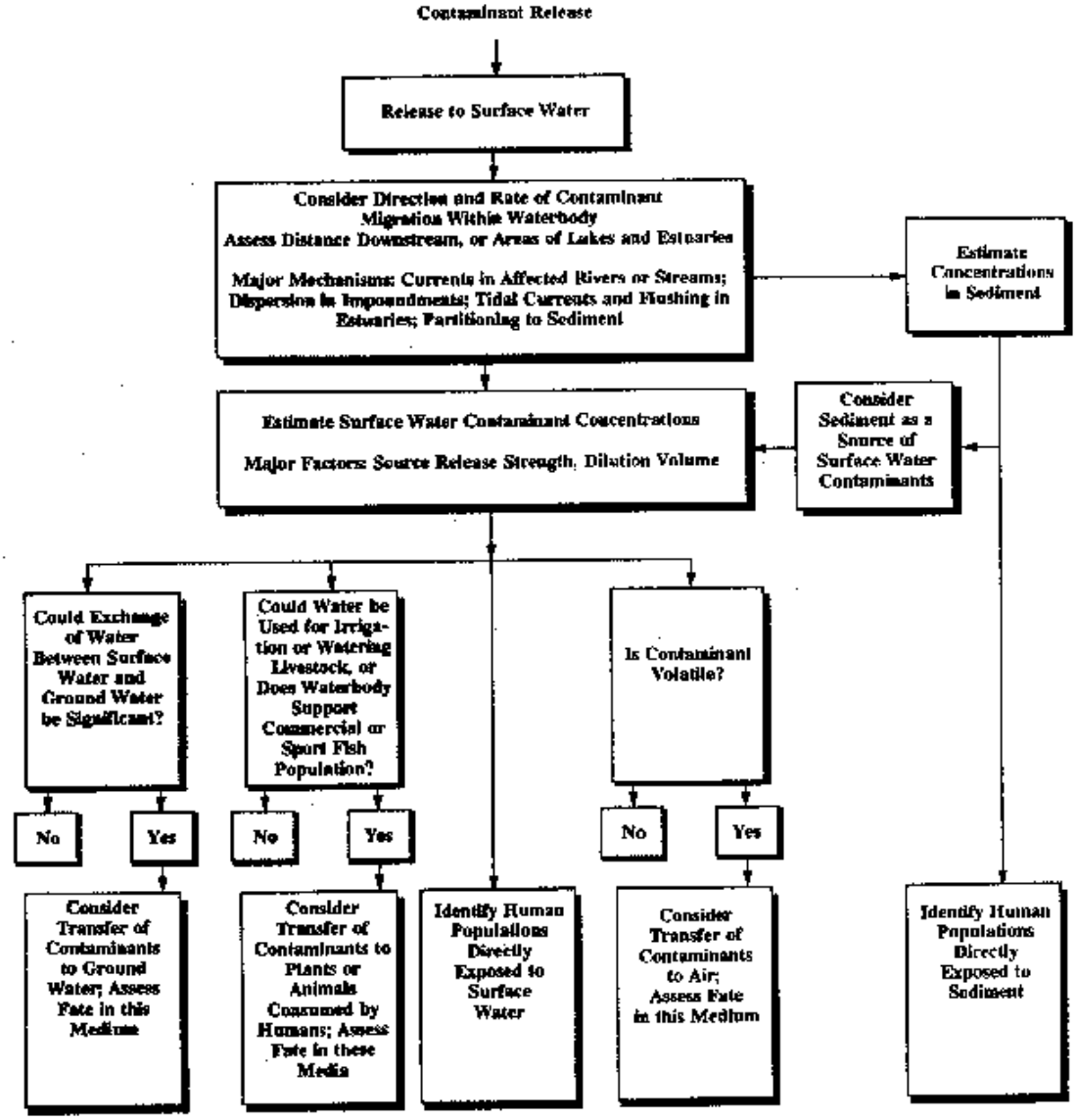

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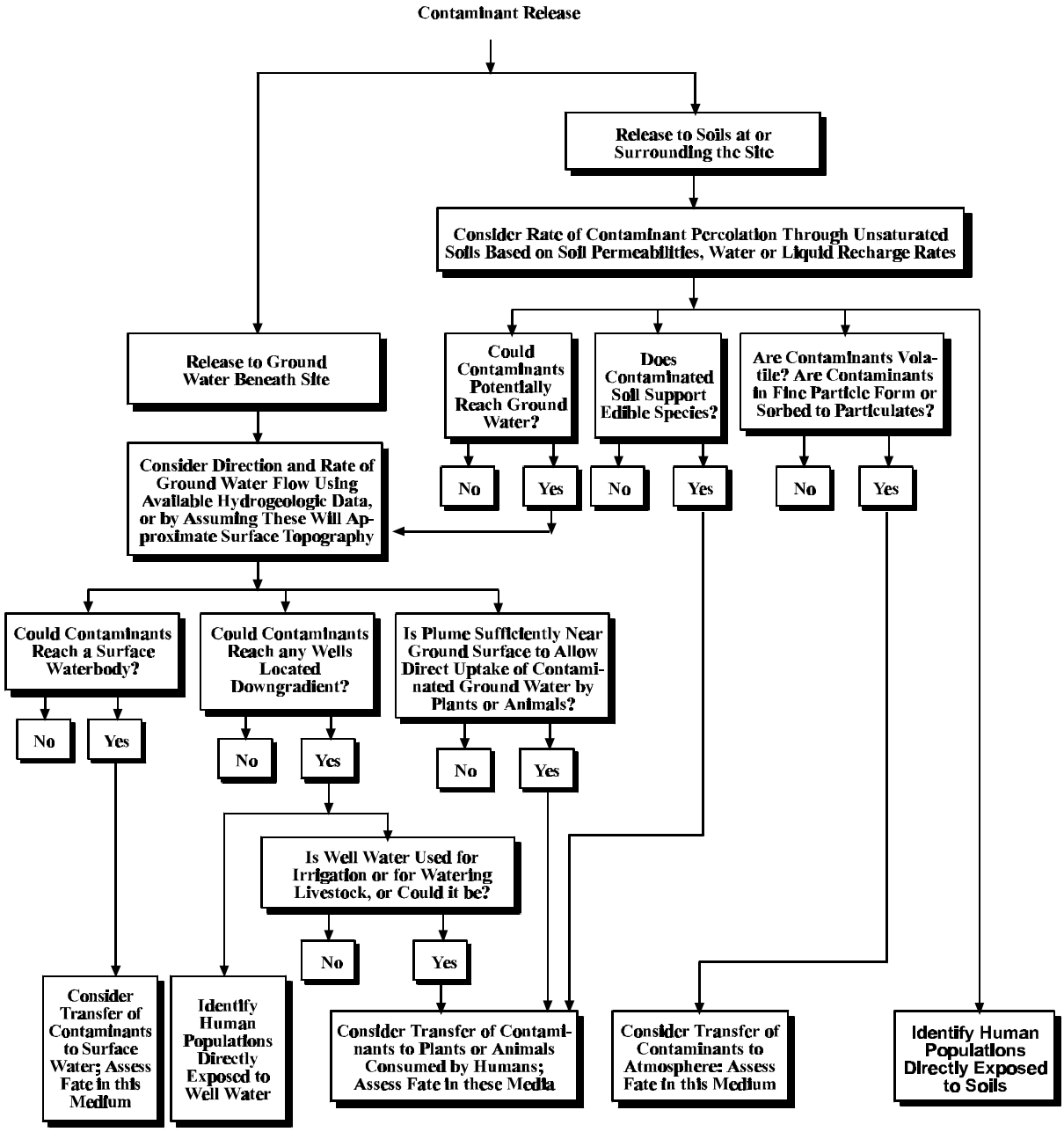
EXHIBIT 6-6 (continued)

FLOW CHART FOR FATE AND TRANSPORT ASSESSMENTS

Environmental fate and transport assessment: soils and ground water



Source: Adapted from EPA 1988b

After determining exposure points, identify probable exposure routes (i.e., ingestion, inhalation, dermal contact) based on the media contaminated and the anticipated activities at the exposure points. In some instances, an exposure point may exist but an exposure route may not (e.g., a person touches contaminated soil but is wearing gloves). Exhibit 6-7 presents a population/exposure route matrix that can be used in determining potential exposure routes at a site.

6.3.4 INTEGRATE INFORMATION ON SOURCES, RELEASES, FATE AND TRANSPORT, EXPOSURE POINTS, AND EXPOSURE ROUTES INTO EXPOSURE PATHWAYS

Assemble the information developed in the previous three steps and determine the complete exposure pathways that exist for the site. A pathway is complete if there is (1) a source or chemical release from a source, (2) an exposure point where contact can occur, and (3) an exposure route by which contact can occur. Otherwise, the pathway is incomplete, such as the situation where there is a source releasing to air but there are no nearby people. If available from ATSDR, human monitoring data indicating chemical accumulation or chemical-related effects in the site area can be used as evidence to support conclusions about which exposure pathways are complete; however, negative data from such studies should not be used to conclude that a pathway is incomplete.

From all complete exposure pathways at a site, select those pathways that will be evaluated further in the exposure assessment. If exposure to a sensitive subpopulation is possible, select that pathway for quantitative evaluation. All pathways should be selected for further evaluation unless there is sound justification (e.g., based on the results of a screening analysis) to eliminate a pathway from detailed analysis. Such a justification could be based on one of the following:

- the exposure resulting from the pathway is much less than that from another pathway involving the same medium at the same exposure point;
- the potential magnitude of exposure from a pathway is low; or
- the probability of the exposure occurring is very low and the risks associated with the occurrence are not high (if a pathway has catastrophic consequences, it should be selected for evaluation even if its probability of occurrence is very low).

Use professional judgment and experience to make these decisions. Before deciding to exclude a pathway from quantitative analysis, consult with the RPM. If a pathway is excluded from further analysis, clearly document the reasons for the decision in the exposure assessment section of the risk assessment report.

For some complete pathways it may not be possible to quantify exposures in the subsequent steps of the analysis because of a lack of data on which to base estimates of chemical release, environmental concentration, or human intake. Available modeling results should complement and supplement the available monitoring data to minimize such problems. However, uncertainties associated with the modeling results may be too large to justify quantitative exposure assessment in the absence of monitoring data to validate the modeling results. These pathways should nevertheless be carried through the exposure assessment so that risks can be qualitatively evaluated or so that this information can be considered during the uncertainty analysis of the results of the exposure assessment (see Section 6.8) and the risk assessment (see Chapter 8).

6.3.5 SUMMARIZE INFORMATION ON ALL COMPLETE EXPOSURE PATHWAYS

Summarize pertinent information on all complete exposure pathways at the site by identifying potentially exposed populations, exposure media, exposure points, and exposure routes. Also note if the pathway has been selected for quantitative evaluation; summarize the justification if a pathway has been excluded. Summarize pathways for current land use and any alternate future land use separately. This summary information is useful for defining the scope of the next step (quantification of exposure) and also is useful as documentation of the exposure pathway analysis. Exhibit 6-8 provides a sample format for presenting this information.

EXHIBIT 6-7
MATRIX OF POTENTIAL EXPOSURE ROUTES

Exposure Medium/ Exposure Route	Residential Population	Commercial/Industrial Population	Recreational Population
Ground Water			
Ingestion	L	A	--
Dermal Contact	L	A	--
Surface Water			
Ingestion	L	A	L,C
Dermal Contact	L	A	L,C
Sediment			
Incidental Ingestion	C	A	C
Dermal Contact	C	A	L,C
Air			
Inhalation of Vapor Phase Chemicals			
Indoors	L	A	--
Outdoors	L	A	L
Inhalation of Particulates			
Indoors	L	A	--
Outdoors	L	A	L
Soil/Dust			
Incidental Ingestion	L,C	A	L,C
Dermal Contact	L,C	A	L,C
Food			
Ingestion			
Fish and Shellfish	L	–	L
Meat and Game	L	–	L
Dairy	L,C	–	L
Eggs	L	–	L
Vegetables	L	–	L

L = lifetime exposure
C = exposure in children may be significantly greater than in adults
A = exposure to adults (highest exposure is likely to occur during occupational activities)

-- = Exposure of this population via this route is not likely to occur.

6.4 STEP 3: QUANTIFICATION OF EXPOSURE: GENERAL CONSIDERATIONS

The next step in the exposure assessment process is to quantify the magnitude, frequency and duration of exposure for the populations and exposure pathways selected for quantitative evaluation. This step is most often conducted in two stages: first, exposure concentrations are estimated, then, pathway-specific intakes are quantified. The specific methodology for calculating exposure concentrations and pathway-specific exposures are presented in Sections 6.5 and 6.6, respectively. This section describes some of the basic concepts behind these processes.

6.4.1 QUANTIFYING THE REASONABLE MAXIMUM EXPOSURE

Exposure is defined as the contact of an organism with a chemical or physical agent. If exposure occurs over time, the total exposure can be divided by a time period of interest to obtain an average exposure rate per unit time. This average exposure rate also can be expressed as a function of body weight. For the purposes of this manual, exposure normalized for time and body weight is termed "intake", and is expressed in units of mg chemical/kg body weight-day.

Exhibit 6-9 presents a generic equation for calculating chemical intakes and defines the intake variables. There are three categories of variables that are used to estimate intake:

(1) chemical-related variable -- exposure concentration;

(2) variables that describe the exposed population -- contact rate, exposure frequency and duration, and body weight; and

(3) assessment-determined variable -- averaging time.

Each intake variable in the equation has a range of values. For Superfund exposure assessments, intake variable values for a given pathway should be selected so that the combination of all intake variables results in an estimate of the reasonable maximum exposure for that pathway. As defined previously, the reasonable maximum exposure (RME) is the maximum exposure that is reasonably expected to occur at a site. Under this approach, some intake variables may not be at their individual maximum values but when in combination with other variables will result in estimates of the RME. Some recommendations for determining the values of the individual intake variables are discussed below. These recommendations are based on EPA's determination of what would result in an estimate of the RME. As discussed previously, a determination of "reasonable" cannot be based solely on quantitative information, but also requires the use of professional judgment. Accordingly, the recommendations below are based on a combination of quantitative information and professional judgment. These are general recommendations, however, and could change based on site-specific information or the particular needs of the risk manager. Consult with the RPM before varying from these recommendations.

Exposure concentration. The concentration term in the intake equation is the arithmetic average of the concentration that is contacted over the exposure period. Although this concentration does not reflect the maximum concentration that could be contacted at any one time, it is regarded as a reasonable estimate of the concentration likely to be contacted over time. This is because in most situations, assuming long-term contact with the maximum concentration is not reasonable. (For exceptions to this generalization, see discussion of hot spots in Section 6.5.3.)

Because of the uncertainty associated with any estimate of exposure concentration, the upper confidence limit (i.e., the 95 percent upper confidence limit) on the arithmetic average will be used for this variable. There are standard statistical methods which can be used to calculate the upper confidence limit on the arithmetic mean. Gilbert (1987, particularly sections 11.6 and 13.2) discusses methods that can be applied to data that are distributed normally or log normally. Kriging is another method that potentially can be used (Clark 1979 is one of several reference books on kriging). A statistician should be consulted for more details or for assistance with specific methods.

EXHIBIT 6-8

EXAMPLE OF TABLE FORMAT FOR SUMMARIZING COMPLETE EXPOSURE PATHWAYS AT A SITE

Potentially Exposed Population	Exposure Route, Medium and Exposure Point	Pathway Selected for Evaluation?	Reason for Selection or Exclusion
Current Land Use			
Residents	Ingestion of ground water from local wells down-gradient of the site	Yes	Residents use ground water from local wells as drinking water.
Residents	Inhalation of chemicals volatilized from ground water during home use	Yes	Some of the chemicals of potential concern in ground water are volatile, and ground water is used by local residents.
Industrial Workers	Direct contact with chemicals of potential concern in soil on the site	Yes	Contaminated soil is in an area potentially used by outside maintenance workers.
Future Land Use			
Residents	Direct contact with chemicals of potential concern in soil on the site	Yes	Area could be developed in the future as a residential area.
Residents	Ingestion of chemicals that have accumulated in fish located in onsite ponds	No	The potential for significant exposure via this pathway is low because none of the chemicals of potential concern accumulate extensively in fish.

EXHIBIT 6-9

GENERIC EQUATION FOR CALCULATING CHEMICAL INTAKES

$$I = C \times CR \times EFD \times \frac{1}{BW} \times \frac{1}{AT}$$

Where:

I = intake; the amount of chemical at the exchange boundary (mg/kg body weight-day)

Chemical-related variable

C = chemical concentration; the average concentration contacted over the exposure period (e.g., mg/liter water)

Variables that describe the exposed population

CR = contact rate; the amount of contaminated medium contacted per unit tine or event (e.g., liters/day)

EFD = exposure frequency and duration; describes how long and how often exposure occurs. Often calculated using two terms (EF and ED):

EF = exposure frequency (days/year)

ED = exposure duration (years)

BW = body weight; the average body weight over the exposure period (kg)

Assessment-determined variable

AT = averaging time; period over which exposure is averaged (days)

If there is great variability in measured or modeled concentration values (such as when too few samples are taken or when model inputs are uncertain), the upper confidence limit on the average concentration will be high, and conceivably could be above the maximum detected or modeled value. In these cases, the maximum detected or modeled value should be used to estimate exposure concentrations. This could be regarded by some as too conservative an estimate, but given the uncertainty in the data in these situations, this approach is regarded as reasonable.

For some sites, where a screening level analysis is regarded as sufficient to characterize potential exposures, calculation of the upper confidence limit on the arithmetic average is not required. In these cases, the maximum detected or modeled concentration should be used as the exposure concentration.

Contact rate. Contact rate reflects the amount of contaminated medium contacted per unit time or event. If statistical data are available for a contact rate, use the 95th percentile value for this variable. (In this case and throughout this chapter, the 90th percentile value can be used if the 95th percentile value is not available.) If statistical data are not available, professional judgment should be used to estimate a value which approximates the 95th percentile value. (It is recognized that such estimates will not be precise. They should, however, reflect a reasonable estimate of an upper-bound value.)

Sometimes several separate terms are used to derive an estimate of contact rate. For example, for dermal contact with chemicals in water, contact rate is estimated by combining information on exposed skin surface area, dermal permeability of a chemical, and exposure time. In such instances, the combination of variables used to estimate intake should result in an estimate approximating the 95th percentile value. Professional judgment will be needed to determine the appropriate combinations of variables. (More specific guidance for determining contact rate for various pathways is given in Section 6.6.)

Exposure frequency and duration. Exposure frequency and duration are used to estimate the total time of exposure. These terms are determined on a site-specific basis. If statistical data are available, use the 95th percentile value for exposure time. In the absence of statistical data (which is usually the case), use reasonable conservative estimates of exposure time. National statistics are available on the upper-bound (90th percentile) and average (50th percentile) number of years spent by individuals at one residence (EPA 1989d). Because of the data on which they are based, these values may underestimate the actual time that someone might live in one residence. Nevertheless, the upper-bound value of 30 years can be used for exposure duration when calculating reasonable maximum residential exposures. In some cases, however, lifetime exposure (70 years by convention) may be a more appropriate assumption. Consult with the RPM regarding the appropriate exposure duration for residential exposures. The exposure frequency and duration selected must be appropriate for the contact rate selected. If a long-term average contact rate (e.g., daily fish ingestion rate averaged over a year) is used, then a daily exposure frequency (i.e., 365 days/year) should be assumed.

Body weight. The value for body weight is the average body weight over the exposure period. If exposure occurs only during childhood years, the average child body weight during the exposure period should be used to estimate intake. For some pathways, such as soil ingestion, exposure can occur throughout the lifetime but the majority of exposure occurs during childhood (because of higher contact rates). In these cases, exposures should be calculated separately for age groups with similar contact rate to body weight ratios; the body weight used in the intake calculation for each age group is the average body weight for that age group. Lifetime exposure is then calculated by taking the time-weighted average of exposure estimates over all age groups. For pathways where contact rate to body weight ratios are fairly constant over a lifetime (e.g., drinking water ingestion), a body weight of 70 kg is used.

A constant body weight over the period of exposure is used primarily by convention, but also because body weight is not always independent of the other variables in the exposure equation (most notably, intake). By keeping body weight constant, error from this dependence is minimized. The average body weight is used because, when combined with the other variable values in the intake equation, it is believed to result in the best estimate of the RME. For example, combining a 95th percentile contact rate with a 5th percentile body weight is not considered reasonable because it is unlikely that smallest person would have the highest intake. Alternatively, combining a 95th percentile intake with a 95th percentile body weight is not considered a maximum because a smaller person could have a higher contact rate to body weight ratio.

Averaging time. The averaging time selected depends on the type of toxic effect being assessed. When evaluating exposures to developmental toxicants, intakes are calculated by averaging over the exposure event (e.g., a day or a single exposure incident). For acute toxicants, intakes are calculated by averaging over the shortest exposure period that could produce an effect, usually an exposure event or a day. When evaluating longer-term exposure to noncarcinogenic toxicants, intakes are calculated by averaging intakes over the period of exposure (i.e., subchronic or chronic daily intakes). For carcinogens, intakes are calculated by prorating the total cumulative dose over a lifetime (i.e., chronic daily intakes, also called lifetime average daily intake). This distinction relates to the currently held scientific opinion that the mechanism of action for each category is different (see Chapter 7 for a discussion). The approach for carcinogens is based on the assumption that a high dose received over a short period of time is equivalent to a corresponding low dose spread over a lifetime (EPA 1986b). This approach becomes problematic as the exposures in question become more intense but less frequent, especially when there is evidence that the agent has shown dose-rate related carcinogenic effects. In some cases, therefore, it may be necessary to consult a toxicologist to assess the level of uncertainty associated with the exposure assessment for carcinogens. The discussion of uncertainty should be included in both the exposure assessment and risk characterization chapters of the risk assessment report.

6.4.2 TIMING CONSIDERATIONS

At many Superfund sites, long-term exposure to relatively low chemical concentrations (i.e., chronic daily intakes) are of greatest concern. In some situations, however, shorter-term exposures (e.g., subchronic daily intakes) also may be important. When deciding whether to evaluate short-term exposure, the following factors should be considered:

- the toxicological characteristics of the chemicals of potential concern;
- the occurrence of high chemical concentrations or the potential for a large release;
- persistence of the chemical in the environment; and
- the characteristics of the population that influence the duration of exposure.

Toxicity considerations. Some chemicals can produce an effect after a single or very short-term exposure to relatively low concentrations. These chemicals include acute toxicants such as skin irritants and neurological poisons, and developmental toxicants. At sites where these types of chemicals are present, it is important to assess exposure for the shortest time period that could result in an effect. For acute toxicants this is usually a single exposure event or a day, although multiple exposures over several days also could result in an effect. For developmental toxicants, the time period of concern is the exposure event. This is based on the assumption that a single exposure at the critical time in development is sufficient to produce an adverse effect. It should be noted that the critical time referred to can occur in almost any segment of the human population (i.e., fertile men and women, the conceptus, and the child up to the age of sexual maturation [EPA 1989e]).

Concentration considerations. Many chemicals can produce an effect after a single or very short-term exposure, but only if exposure is to a relatively high concentration. Therefore, it is important that the assessor identify possible situations where a short-term exposure to a high concentration could occur. Examples of such a situation include sites where contact with a small, but highly contaminated area is possible (e.g., a source or a hot spot), or sites where there is a potential for a large chemical release (e.g., explosions, ruptured drums, breached lagoon dikes). Exposure should be determined

for the shortest period of time that could produce an effect.

Persistence considerations. Some chemicals may degrade rapidly in the environment. In these cases, exposures should be assessed only for that period of time in which the chemical will be present at the site. Exposure assessments in these situations may need to include evaluations of exposure to the breakdown products, if they are persistent or toxic at the levels predicted to occur at the site.

Population considerations. At some sites, population activities are such that exposure would occur only for a short time period (a few weeks or months), infrequently, or intermittently. Examples of this would be seasonal exposures such as during vacations or other recreational activities. The period of time over which exposures are averaged in these instances depends on the type of toxic effect being assessed (see previous discussion on averaging time, Section 6.4.1).

6.5 QUANTIFICATION OF EXPOSURE: DETERMINATION OF EXPOSURE CONCENTRATIONS

This section describes the basic approaches and methodology for determining exposure concentrations of the chemicals of potential concern in different environmental media using available monitoring data and appropriate models. As discussed in Section 6.4.1, the concentration term in the exposure equation is the average concentration contacted at the exposure point or points over the exposure period. When estimating exposure concentrations, the objective is to provide a conservative estimate of this average concentration (e.g., the 95 percent upper confidence limit on the arithmetic mean chemical concentration).

This section provides an overview of the basic concepts and approaches for estimating exposure concentrations. It identifies what type of information is needed to estimate concentrations, where to find it, and how to interpret and use it. This section is not designed to provide all the information necessary to derive exposure concentrations and, therefore, does not detail the specifics of potentially applicable models nor provide the data necessary to run the models or support concentration estimates. However, sources of such information, including the *Superfund Exposure Assessment Manual* (SEAM; EPA 1988b) are referenced throughout the discussion.

6.5.1 GENERAL CONSIDERATIONS FOR ESTIMATING EXPOSURE CONCENTRATIONS

In general, a great deal of professional judgment is required to estimate exposure concentrations. Exposure concentrations may be estimated by (1) using monitoring data alone, or (2) using a combination of monitoring data and environmental fate and transport models. In most exposure assessments, some combination of monitoring data and environmental modeling will be required to estimate exposure concentrations.

Direct use of monitoring data . Use of monitoring data to estimate exposure concentrations is normally applicable where exposure involves direct contact with the monitored medium (e.g., direct contact with chemicals in soil or sediment), or in cases where monitoring has occurred directly at an exposure point (e.g., a residential drinking water well or public water supply). For these exposure pathways, monitoring data generally provide the best estimate of current exposure concentrations.

As the first step in estimating exposure concentrations, summarize available monitoring data. The manner in which the data are summarized depends upon the site characteristics and the pathways being evaluated. It may be necessary to divide chemical data from a particular medium into subgroups based on the location of sample points and the potential exposure pathways. In other instances, as when the sampling point is an exposure point (e.g., when the sample is from an existing drinking water well) it may not be appropriate to group samples at all, but may be most appropriate to treat the sample data separately when estimating intakes. Still,

in other instances, the assessor may wish to use the maximum concentration from a medium as the exposure concentration for a given pathway as a screening approach to place an upper bound on exposure. In these cases it is important to remember that if a screening level approach suggests a potential health concern, the estimates of exposure should be modified to reflect more probable exposure conditions.

In those instances where it is appropriate to group sampling data from a particular medium, calculate for each exposure medium and each chemical the 95 percent upper confidence limit on the arithmetic average chemical concentration. See Chapter 5 for guidance on how to treat sample concentrations below the quantitation limit.

Modeling approaches . In some instances, it may not be appropriate to use monitoring data alone, and fate and transport models may be required to estimate exposure concentrations. Specific instances where monitoring data alone may not be adequate are as follows.

- Where exposure points are spatially separate from monitoring points. Models may be required when exposure points are remote from sources of contamination if mechanisms for release and transport to exposure points exist (e.g., ground-water transport, air dispersion).

- Where temporal distribution of data is lacking. Typically, data from Superfund investigations are collected over a relatively short period of time. This generally will give a clear indication of current site conditions, but both long-term and short-term exposure estimates usually are required in Superfund exposure assessments. Although there may be situations where it is reasonable to assume that concentrations will remain constant over a long period of time, in many cases the time span of the monitoring data is not adequate to predict future exposure concentrations. Environmental models may be required to make these predictions.

- Where monitoring data are restricted by the limit of quantitation. Environmental models may be needed to predict concentrations of contaminants that may be present at concentrations that are below the quantitation limit but that may still cause toxic effects (even at such low concentrations). For example, in the case of a ground-water plume discharging into a river, the dilution afforded by the river may be sufficient to reduce the concentration of the chemical to a level that could not be detected by direct monitoring. However, as discussed in Section 5.3.1, the chemical may be sufficiently toxic or bioaccumulative that it could present a health risk at concentrations below the limit of quantitation. Models may be required to make exposure estimates in these types of situations.

A wide variety of models are available for use in exposure assessments. SEAM (EPA 1988b) and the *Exposure Assessment Methods Handbook* (EPA 1989f) describe some of the models available and provide guidance in selecting appropriate modeling techniques. Also, the Center for Exposure Assessment Modeling (CEAM -- Environmental Research Laboratory (ERL) Athens), the Source Receptor Analysis Branch (Office of Air Quality Planning and Standards, or OAQPS), and modelers in EPA regional offices can provide assistance in selecting appropriate models. Finally, Volume IV of the NTGS (EPA 1989c) provides guidance for air and atmospheric dispersion modeling for Superfund sites. Be sure to discuss the fate and transport models to be used in the exposure assessment with the RPM.

The level of effort to be expended in estimating exposure concentrations will depend on the type and quantity of data available, the level of detail required in the assessment, and the resources available for the assessment. In general, estimating exposure concentrations will involve analysis of site monitoring data and application of simple, screening-level analytical models. The most important factor in determining the level of effort will be the quantity and quality of the available data. In general, larger data sets will support the use of more sophisticated models.

Other considerations . When evaluating chemical contamination at a site, it is important to review the spatial distribution of the data and evaluate it in ways that have the most relevance to the pathway being assessed. In short, consider where the contamination is with respect to known or anticipated population activity patterns. Maps of both concentration distribution and activity patterns will be useful for the exposure assessment. It is the intersection of activity patterns and contamination that defines an exposure area. Data from random sampling or from systematic grid pattern sampling may be more representative of a given exposure pathway than data collected only from hot spots.

Generally, verified GC/MS laboratory data with adequate quality control will be required to support quantitative exposure assessment. Field screening data generally cannot be incorporated when estimating exposure concentrations because they are derived using less sensitive analytical methods and are subject to less stringent quality control.

Other areas to be considered in estimating exposure concentrations are as follows.

- Steady-state vs. non-steady-state conditions. Frequently, it may be necessary to assume steady-state conditions because the information required to estimate non-steady-state conditions (such as source depletion rate) is not readily available. This is likely to overestimate long-term exposure concentrations for certain pathways.

- Number and type of exposure parameters that must be assumed. In developing exposure models, values for site-specific parameters such as hydraulic conductivity, organic carbon content of soil, wind speed and direction, and soil type may be required. These values may be generated as part of the RI. In cases where these values are not available, literature values may be substituted. In the absence of applicable literature values, the assessor must consider if a reliable exposure concentration estimate can be made.

- Number and type of fate processes to be considered. In some cases, exposure modeling may be limited to considerations of mass balance, dilution, dispersion, and equilibrium partitioning. In other cases, models of more complex fate processes, such as chemical reaction, biodegradation, and photolysis may be needed. However, prediction of such fate processes requires significantly larger quantities of model calibration and validation data than required for less complex fate processes. For those sites where these more complex fate processes need to be modeled, be sure to consult with the RPM regarding the added data requirements.

6.5.2 ESTIMATE EXPOSURE CONCENTRATIONS IN GROUND WATER

Exposure concentrations in ground water can be based on monitoring data alone or on a combination of monitoring and modeling. In some cases, the exposure assessor may favor the use of monitoring data over the use of complex models to develop exposure concentrations. It is most appropriate to use ground-water sampling data as estimates of exposure concentrations when the sampling points correspond to exposure points, such as samples taken from a drinking water tap. However, samples taken directly from a domestic well or drinking water tap should be interpreted cautiously. For example, where the water is acidic, inorganic chemicals such as lead or copper may leach from the distribution system. Organic chemicals such as phthalates may migrate into water from plastic piping. Therefore, interpretations of these data should consider the type and operation of the pumping, storage, and distribution system involved.

Most of the time, data from monitoring wells will be used to estimate chemical concentrations at the exposure point. Several issues should be considered when using monitoring well data to estimate these concentrations. First, determine if the aquifer has sufficient production capacity and is of sufficient quality to support drinking water or other uses. If so, it generally should be assumed that water could be drawn from anywhere in the aquifer, regardless of the location of existing wells relative to the

contaminant plume. In a few situations, however, it may not be reasonable to assume that water will be drawn from directly beneath a specific source (e.g., a waste management unit such as a landfill) in the future. In these cases, it should be assumed that water could be drawn from directly adjacent to the source. Selection of the location(s) used to evaluate future ground-water exposures should be made in consultation with the RPM. Second, compare the construction of wells (e.g., drinking water wells) in the area with the construction of the monitoring wells. For example, drinking water wells may draw water from more than one aquifer, whereas individual monitoring wells are usually screened in a specific aquifer. In some cases it may be appropriate to separate data from two aquifers that have very limited hydraulic connection if drinking water wells in the area draw water from only one of them. Consult a hydrogeologist for assistance in the above considerations.

Another issue to consider is filtration of water samples. While filtration of ground-water samples provides useful information for understanding chemical transport within an aquifer (see Section 4.5.3 for more details), the use of filtered samples for estimating exposure is very controversial because these data may underestimate chemical concentrations in water from an unfiltered tap. Therefore, data from unfiltered samples should be used to estimate exposure concentrations. Consult with the RPM before using data from filtered samples.

Ground-water monitoring data are often of limited use for evaluating long-term exposure concentrations because they are generally representative of current site conditions and not long-term trends. Therefore, ground-water models may be needed to estimate exposure concentrations. Monitoring data should be used when possible to calibrate the models.

Estimating exposure concentrations in ground water using models can be a complex task because of the many physical and chemical processes that may affect transport and transformation in ground water. Among the important mechanisms that should be considered when estimating exposure concentrations in ground water are leaching from the surface, advection (including infiltration, flow through the unsaturated zone, and flow with ground water), dispersion, sorption (including adsorption, desorption, and ion exchange), and transformation (including biological degradation, hydrolysis, oxidation, reduction, complexation, dissolution, and precipitation). Another consideration is that not all chemicals may be dissolved in water, but may be present instead in nonaqueous phases that float on top of ground water or sink to the bottom of the aquifer.

The proper selection and application of soil and ground-water models requires a thorough understanding of the physical, chemical, and hydrogeologic characteristics of the site. SEAM (EPA 1988b) provides a discussion of the factors controlling soil and ground-water contaminant migration as well as descriptions of various soil and ground-water models. For more in-depth guidance on the selection and application of appropriate ground-water models, consult *Selection Criteria for Mathematical Models Used in Exposure Assessments: Ground-water Models* (EPA 1988c). As with all modeling, the assessor should carefully evaluate the applicability of the model to the site being evaluated, and should consult with a hydrogeologist as necessary.

If ground-water modeling is not used, current concentrations can be used to represent future concentrations in ground water assuming steady-state conditions. This assumption should be noted in the exposure assessment chapter and in the uncertainties and conclusions of the risk assessment.

6.5.3 ESTIMATE EXPOSURE CONCENTRATIONS IN SOIL

Estimates of current exposure concentrations in soil can be based directly on summarized monitoring data if it is assumed that concentrations remain constant over time. Such an assumption may not be appropriate for some chemicals and some sites where leaching, volatilization, photolysis, biodegradation, wind erosion, and surface runoff will reduce chemical concentrations over time. Soil monitoring data and site conditions should be carefully screened to identify situations where source depletion is likely to be important. SEAM (EPA 1988b) gives steady-state equations for estimating many of these processes. However, incorporating these processes into the calculation of exposure concentrations for soil involves considerable effort. If a modeling approach is not adopted in these situations, assume a constant concentration over time and base exposure concentrations on monitoring data. This assumption should be clearly documented.

In evaluating monitoring data for the assessment of soil contact exposures, the spatial distribution of the data is a critical factor. The spatial distribution of soil contamination can be used as a basis for estimating the average concentrations contacted over time if it is assumed that contact with soil is spatially random (i.e., if

contact with soil in all areas of the site is equally probable). Data from random sampling programs or samples from evenly spaced grid networks generally can be considered as representative of concentrations across the site. At many sites however, sampling programs are designed to characterize only obviously contaminated soils or hot spot areas. Care must be taken in evaluating such data sets for estimating exposure concentrations. Samples from areas where direct contact is not realistic (such as where a steep slope or thick vegetation prevents current access) should not be considered when estimating current exposure concentrations for direct contact pathways. Similarly, the depth of the sample should be considered; surface soil samples should be evaluated separately from subsurface samples if direct contact with surface soil or inhalation of wind blown dust are potential exposure pathways at the site.

In some cases, contamination may be unevenly distributed across a site, resulting in hot spots (areas of high contamination relative to other areas of the site). If a hot spot is located near an area which, because of site or population characteristics, is visited or used more frequently, exposure to the hot spot should be assessed separately. The area over which the activity is expected to occur should be considered when averaging the monitoring data for a hot spot. For example, averaging soil data over an area the size of a residential backyard (e.g., an eighth of an acre) may be most appropriate for evaluating residential soil pathways.

6.5.4 ESTIMATE EXPOSURE CONCENTRATIONS IN AIR

There are three general approaches to estimating exposure concentrations in air: (1) ambient air monitoring, (2) emission measurements coupled with dispersion modeling, and (3) emission modeling coupled with dispersion modeling. Whichever approach is used, the resulting exposure concentrations should be as representative as possible of the specific exposure pathways being evaluated. If long-term exposures are being evaluated, the exposure concentrations should be representative of long-term averages. If short-term exposures are of interest, measured or modeled peak concentrations may be most representative.

If monitoring data have been collected at a site, their adequacy for use in a risk assessment should be evaluated by considering how appropriate they are for the exposures being addressed. Volume II of the NTGS (EPA 1989b) provides guidance for measuring emissions and should be consulted when evaluating the appropriateness of emission data. See Chapter 4 (Section 4.5.5) for factors to consider when evaluating the appropriateness of ambient air monitoring data. As long as there are no significant analytical problems affecting air sampling data, background levels are not significantly higher than potential site-related levels, and site-related levels are not below the instrument detection limit, air monitoring data can be used to derive exposure concentrations. There still will be uncertainties inherent in using these data because they usually are not representative of actual long-term average air concentrations. This may be because there were only a few sample collection periods, samples were collected during only one type of meteorological or climatic condition, or because the source of the chemicals will change over time. These uncertainties should be mentioned in the risk assessment.

In the absence of monitoring data, exposure concentrations often can be estimated using models. Two kinds of models are used to estimate air concentrations: emission models that predict the rate at which chemicals may be released into the air from a source, and dispersion models that predict associated concentrations in air at potential receptor points.

Outdoor air modeling. Emissions may occur as a result of the volatilization of chemicals from contaminated media or as a result of the suspension of onsite soils. Models that predict emission rates for volatile chemicals or dust require numerous input parameters, many of which are site-specific. For volatile chemicals, emission models for surface water and soil are available in SEAM (EPA 1988b). Volume IV of the NTGS (EPA 1989c) also provides guidance for evaluating volatile emissions at Superfund sites. Emissions due to suspension of soils may result from wind erosion of exposed soil particles and from vehicular disturbances of the soil. To predict soil or dust emissions, EPA's fugitive dust models provided in AP42 (EPA 1985b) or models described in SEAM (1988b) may be used. Volume IV of the NTGS (EPA 1989c) also will be useful in evaluating fugitive dust emissions at Superfund sites. Be sure to critically review all models before use to determine their applicability to the situation and site being evaluated. If necessary, consult with air modelers in EPA regional offices, the Exposure

Assessment Group in EPA headquarters or the Source Receptor Analysis Branch in OAQPS.

After emissions have been estimated or measured, air dispersion models can be applied to estimate air concentrations at receptor points. In choosing a dispersion model, factors that must be considered include the type of source and the location of the receptor relative to the source. For area or point sources, EPA's Industrial Source Complex model (EPA 1987a) or the simple Gaussian dispersion models discussed in SEAM (EPA 1988b) can provide air concentrations around the source. Other models can be found in Volume IV of the NTGS (EPA 1989c). The Source Receptor Analysis Branch of OAQPS also can be contacted for assistance. Again, critically review all models for their applicability.

Indoor air modeling. Indoor emissions may occur as a result of transport of outdoor-generated dust or vapors indoors, or as a result of volatilization of chemicals indoors during use of contaminated water (e.g., during showering, cooking, washing). Few models are available for estimating indoor air concentrations from outside sources. For dust transport indoors, it can generally be assumed that indoor concentrations are less than those outdoors. For vapor transport indoors, concentrations indoors and outdoors can be assumed to be equivalent in most cases. However, at sites where subsurface soil gas or ground-water seepage are entering indoors, vapor concentrations inside could exceed those outdoors. Vapor concentrations resulting from indoor use of water may be greater than those outdoors, depending on the emission source characteristics, dispersion indoors, and indoor-outdoor air exchange rates. Use models discussed in the *Exposure Assessment Methods Handbook* (EPA 1989f) to evaluate volatilization of chemicals from indoor use of water.

6.5.5 ESTIMATE EXPOSURE CONCENTRATIONS IN SURFACE WATER

Data from surface water sampling and analysis may be used alone or in conjunction with fate and transport models to estimate exposure concentrations. Where the sampling points correspond to exposure points, such as at locations where fishing or recreational activities take place, or at the intake to a drinking water supply, the monitoring data can be used alone to estimate exposure concentrations. However, the data must be carefully screened. The complexity of surface water processes may lead to certain limitations in monitoring data. Among these are the following.

- **Temporal representativeness .** Surface water bodies are subject to seasonal changes in flow, temperature, and depth that may significantly affect the fate and transport of contaminants. Releases to surface water bodies often depend on storm conditions to produce surface runoff and soil erosion. Lakes are subject to seasonal stratification and changes in biological activity. Unless the surface water monitoring program has been designed to account for these phenomena, the data may not represent long-term average concentrations or short-term concentrations that may occur after storm events.

- **Spatial representativeness .** Considerable variation in concentration can occur with respect to depth and lateral location in surface water bodies. Sample locations should be examined relative to surface water mixing zones. Concentrations within the mixing zone may be significantly higher than at downstream points where complete mixing has taken place.

- **Quantitation limit limitations.** Where large surface water bodies are involved, contaminants that enter as a result of ground-water discharge or runoff from relatively small areas may be significantly diluted. Although standard analytical methods may not be able to detect chemicals at these levels, the toxic effects of the chemicals and/or their potential to bioaccumulate may nevertheless require that such concentrations be assessed.

- **Contributions from other sources.** Surface water bodies are normally subject to contamination from many sources (e.g., pesticide runoff, stormwater, wastewater discharges, acid mine drainage). Many of the chemicals associated with these sources may be difficult to distinguish from site-related chemicals. In many cases background samples will be useful in assessing site-related contaminants from other contaminants (see Section 4.4). However, there may be other cases where a release and transport model may be required to make the distinction.

Many analytical and numerical models are available to estimate the release of contaminants to surface water

and to predict the fate of contaminants once released. The models range from simple mass balance relationships to numerical codes that contain terms for chemical and biological reactions and interactions with sediments. In general, the level of information collected during the RI will tend to limit the use of the more complex models.

There are several documents that can be consulted when selecting models to estimate surface water exposure concentrations, including SEAM (EPA 1988b), the *Exposure Assessment Methods Handbook* (EPA 1989f), and *Selection Criteria for Mathematical Models Used in Exposure Assessments: Surface Water Models* (EPA 1987b). SEAM lists equations for surface water runoff and soil erosion and presents the basic mass balance relationships for estimating the effects of dilution. A list of available numerical codes for more complex modeling also is provided. The selection criteria document (EPA 1987b) provides a more in-depth discussion of numerical codes and other models. In addition, it provides guidelines and procedures for evaluating the appropriate level of complexity required for various applications. The document lists criteria to consider when selecting a surface water model, including: (1) type of water body, (2) presence of steady-state or transient conditions, (3) point versus non-point sources of contamination, (4) whether 1, 2, or 3 spatial dimensions should be considered, (5) the degree of mixing, (6) sediment interactions, and (7) chemical processes. Each of the referenced documents should be consulted prior to any surface water modeling.

6.5.6 ESTIMATE EXPOSURE CONCENTRATIONS IN SEDIMENTS

In general, use sediment monitoring data to estimate exposure concentrations. Sediment monitoring data can be expected to provide better temporal representativeness than surface water concentrations. This will especially be true in the case of contaminants such as PCBs, PAHs, and some inorganic chemicals, which are likely to remain bound to the sediments. When using monitoring data to represent exposure concentrations for direct contact exposures, data from surficial, near-shore sediments should be used.

If modeling is needed to estimate sediment exposure concentrations, consult SEAM (EPA 1988b). SEAM treats surface water and sediment together for the purpose of listing available models for the release and transport of contaminants. Models for soil erosion releases are equally applicable for estimating exposure concentrations for surface water and sediment. Many of the numerical models listed in SEAM and the surface water selection criteria document (EPA 1987b) contain sections devoted to sediment fate and transport.

6.5.7 ESTIMATE CHEMICAL CONCENTRATIONS IN FOOD

Fish and shellfish. Chemical concentrations in fish and shellfish may be measured or estimated. Site-specific measured values are preferable to estimated values, but before using such values, evaluate the sampling plan to determine if it was adequate to characterize the population and species of concern (see Section 4.5.6 for some sampling considerations). Also examine analytical procedures to determine if the quantitation limits were low enough to detect the lowest concentration potentially harmful to humans. Inadequate sampling or high levels of quantitation may lead to erroneous conclusions.

In the absence of adequate tissue measurements, first consider whether the chemical bioconcentrates (i.e., is taken up from water) or bioaccumulates (i.e., is taken up from food, sediment, and water). For example, low molecular weight volatile organic chemicals do not bioaccumulate in aquatic organisms to a great extent. Other chemicals accumulate in some species but not in others. For example, PAHs tend to accumulate in mollusk species but not in fish, which rapidly metabolize the chemicals. For those chemicals that bioconcentrate in aquatic species of concern, use the organism/water partition coefficient (i.e., bioconcentration factor, or BCF) approach to estimate steady-state concentrations. BCFs that estimate concentrations in edible tissue (muscle) are generally more appropriate for assessing human exposures from fish or shellfish ingestion than those that estimate concentrations in the whole body, although this is not true for all aquatic species or applicable to all human populations consuming fish or shellfish. When data from multiple experiments are available, select the BCF from a test that used a species most similar to the species of concern at the site, and multiply the BCF directly by the dissolved chemical concentration in water to obtain estimates of tissue concentrations. Be aware that the study from which the BCF is obtained should reflect a steady state or equilibrium condition, generally achieved over long-term exposures (although some chemicals may reach steady state rapidly in certain species). For some chemicals, BCFs may overestimate tissue levels in fish that may be exposed only for a short period of time.

When no BCF is available, estimate the BCF with a regression equation based on octanol/water partition coefficients (K_{ow}). Several equations are available in the literature. Those developed for chemicals with structural similarities to the chemical of concern should be used in preference to general equations because of better statistical correlations.

The regression equation approach to estimating BCFs can overestimate or underestimate concentrations in fish tissue depending upon the chemical of concern and the studies used to develop the regression equations. For example, high molecular weight PAHs (such as benz(a)pyrene) with high K_{ow} values lead to the prediction of high fish tissue residues. However, PAHs are rapidly metabolized in the liver, and do not appear to accumulate significantly in fish. Regression equations using K_{ow} cannot take into account such pharmacokinetics, and thus may overestimate bioconcentration. On the other hand, studies used to develop regression equations which were not representative of steady-state conditions will tend to underestimate BCFs.

Typical methods for estimating fish tissue concentrations are based on dissolved chemical concentrations in water. While chemicals present in sediment and biota may also bioaccumulate in fish, there are only limited data available to estimate contributions to fish from these sources. However, chemicals that readily adsorb to sediments, such as PCBs, can be present in surface water at concentrations below detection limits and still significantly bioaccumulate. Some models are available to assess the contribution of chemical concentrations in sediment to chemical concentrations in aquatic biota. CEAM (ERL Athens) may be of assistance in choosing and applying an appropriate model.

Plants. Site-related chemicals may be present in plants as a result of direct deposition onto plant surfaces, uptake from the soil, and uptake from the air. When possible, samples of plants or plant products should be used to estimate exposure concentrations. In the absence of monitoring data, several modeling approaches are available for estimating exposure concentrations in plants. Use of these models, however, can introduce substantial uncertainty into an exposure assessment.

If deposition onto plants is the source of the chemical, air deposition modeling can be used in conjunction with plant interception fractions to estimate uptake. The plant interception fraction can be estimated by methods published in the literature or can be developed for a specific crop by considering crop yield and the area of the plant available for deposition.

If soil contamination is the source of the chemical, calculate the concentration in plants by multiplying soil to plant partition coefficients by soil concentrations. Use the open literature or computerized data bases to obtain these coefficients from field, microcosm, or laboratory experiments that are applicable to the type of vegetation or crop of concern (see EPA 1985c sludge documents for some). In the absence of more specific information, use general BCFs published in the literature that are not crop-specific (see Baes *et al*. 1984 for some). When using these parameters, it is important to consider that many site-specific factors affect the extent of uptake. These factors include pH, the amount of organic material present in soil, and the presence of other chemicals.

When literature values are not available, consider equations published in the literature for estimating uptake into the whole plant, into the root, and translocation from the root into above ground parts (see Calamari *et al*. 1987). Such methods require physical/chemical parameters such as K_{ow} or molecular weight and were developed using a limited data base. Scientific judgment must always be applied in the development and application of any partition coefficient, and caution must be applied in using these values in risk assessment.

Terrestrial animals. Use tissue monitoring data when available and appropriate for estimating human exposure to chemicals in the terrestrial food chain. In the absence of tissue monitoring data, use transfer coefficients together with the total chemical mass ingested by an animal per day to estimate contaminant concentrations in meat, eggs, or milk. Data to support modeling of uptake by terrestrial animals generally are not available for birds, but are available for some mammalian species. Terrestrial mammals such as cattle are simultaneously exposed to chemicals from several sources such as water, soil, corn silage, pasture grass, and hay. Cattle ingest varying amounts of these sources per day, each of which will contain a different contaminant concentration. Because all sources can be important with regard to total body burden, an approach based upon the daily mass of chemical ingested per day is recommended because it can be applied to input from many sources.

Obtain transfer coefficients from the literature (see Ng *et al*. 1977, 1979, 1982; Baes *et al*. 1984 for some), or calculate them directly from feeding studies (see Jensen *et al*. 1981; Jensen and Hummel 1982; Fries *et al*. 1973; Van Bruwaene *et al*. 1984). In the absence of this information, use regression equations in the literature for the estimation of transfer coefficients (see Travis and Arms 1988). It is important to be aware that regression equations that use feeding study results from short-term exposures may underestimate meat or milk concentrations. In addition, regression equations which rely on K_{ow} values may overestimate exposures for chemicals such as benz(a)pyrene that are rapidly metabolized. Information on the amount of feed, soil and water ingested by dairy and beef cows is available in the literature and should be combined with chemical concentrations in these media to estimate a daily dose to the animal.

6.5.8 SUMMARIZE EXPOSURE CONCENTRATIONS FOR EACH PATHWAY

Summarize the exposure concentrations derived for each pathway. Exhibit 6-10 presents a sample format.

6.6 QUANTIFICATION OF EXPOSURE: ESTIMATION OF CHEMICAL INTAKE

This section describes the methodology for calculating chemical-specific intakes for the populations and exposure pathways selected for quantitative evaluation. The general equation for estimating intake was shown in Exhibit 6-9. Remember that the intakes calculated in this step are expressed as the amount of chemical at the exchange boundary (e.g., skin, lungs, gut) and available for absorption. Intake, therefore, is not equivalent to absorbed dose, which is the amount of a chemical absorbed into the blood stream.

EXHIBIT 6-10

EXAMPLE OF TABLE FORMAT FOR SUMMARIZING EXPOSURE CONCENTRATIONS

Populations/Pathways	Exposure Concentration	Comments
Current Residents		
Ingestion of ground water:		
Benzene	9 ug/L	Concentrations are the 95 percent upper confidence limit on the arithmetic average of measured concentrations in downgradient monitoring wells.
Chlordane	5.3 ug/L	
Cyanide	11 ug/L	
Direct contact with soil:		
Manganese	1200 mg/kg	Concentrations are the 95 percent upper confidence limit on the arithmetic average of measured concentrations in onsite surface soils.
Selenium	48 mg/kg	
Mercury	2 mg/kg	
Inhalation of dust:		
Manganese	1 mg/m^3	Concentrations are based on estimates of fugitive dust generation and dispersion to nearby homes. Concentration inputs for air model are 95 percent upper confidence limit on the arithmetic average of measured concentrations in onsite soil.
Selenium	0.04 mg/m^3	
Mercury	0.002 mg/m^3	

The sections that follow give standard equations for estimating human intakes for all possible exposure routes at a site. Values for equation variables are presented for use in evaluating residential exposures. Considerations for deriving pathway-specific variable values for populations other than residential (i.e., commercial/industrial or recreational) also are given. In general, both upper-bound (e.g., 95th percentile or maximum values) and average (mean or median) values are presented. These values can be used to calculate the RME or to evaluate uncertainty. A general discussion of which variable values should be used to calculate the RME was provided in Section 6.4.1; more specific guidance follows. A discussion of the uncertainty analysis is presented in Section 6.8.

The information presented below is organized by exposure medium and exposure route.

6.6.1 CALCULATE GROUND-WATER AND SURFACE WATER INTAKES

Individuals may be exposed to chemicals of potential concern in ground water and surface water by the following routes:

(1) ingestion of ground water or surface water used as drinking water;

(2) incidental ingestion of surface water while swimming; and

(3) dermal contact with ground water or surface water.

Inhalation exposures to chemicals that have volatilized from surface or ground water are covered in Section 6.6.3.

Intake from drinking water. Calculate residential intakes from ingestion of ground water or surface water used as drinking water, using the equation and variable values presented in Exhibit 6-11. As discussed in section 6.5.3, chemical concentration in water (CW) should be based on data from unfiltered samples. Develop pathway-specific variable values as necessary. Ingestion rates (IR) could be lower for residents who spend a portion of their day outside the home (e.g., at work). Also, exposure frequency (EF) may vary with land use. Recreational users and workers generally would be exposed less frequently than residents.

Intake from ingestion of surface water while swimming. Calculate intakes from incidental ingestion of surface water while swimming. Use the equation and variable values presented in Exhibit 6-12. Chemical concentration in water (CW) should represent unfiltered concentrations. Incidental ingestion rates (IR) while swimming have not been found in the available literature. SEAM (EPA 1988b) recommends using an incidental ingestion rate of 50 ml/hour of swimming. Exposure duration (ED) will generally be less for recreational users of a surface water compared to residents living near the surface water. Workers are not expected to be exposed via this pathway.

Intake from dermal contact. Calculate intakes from dermal contact with water while swimming, wading, etc., or during household use (e.g., bathing).

Use the equation and variable values presented in Exhibit 6-13. In this case, the calculated exposure is actually the absorbed dose, not the amount of chemical that comes in contact with the skin (i.e., intake). This is because permeability constants (PC) reflect the movement of the chemical across the skin to the stratum corneum and into the bloodstream. Be sure to record this information in the summary of exposure assessment results so that the calculated intake is compared to an appropriate toxicity reference value in the risk characterization chapter. Note that PC are based on an equilibrium partitioning and likely result in an over-estimation of absorbed dose over short exposure periods (e.g., < 1 hr). The open literature should be consulted for chemical-specific PC values. The values in SEAM (EPA 1988b) are currently being reviewed and should not be used at this time. If chemical-specific PC values are not available, the permeability of water can be used to derive a default value. (See Blank *et al.* [1984] for some values [e.g., 8.4×10^{-4} cm/hr].) Note that this approach may underestimate dermal permeability for some organic chemicals.

EXHIBIT 6-11

RESIDENTIAL EXPOSURE: INGESTION OF CHEMICALS IN DRINKING WATER [a] (AND BEVERAGES MADE USING DRINKING WATER)

Equation:

$$\text{Intake (mg/kg-day)} = \frac{CW \times IR \times EF \times ED}{BW \times AT}$$

Where:

CW = Chemical Concentration in Water (mg/liter)
IR = Ingestion Rate (liters/day)
EF = Exposure Frequency (days/year)
ED = Exposure Duration (years)
BW = Body Weight (kg)
AT = Averaging time (period over which exposure is averaged -- days)

Variable Values:

CW: Site-specific measured or modeled value

IR: 2 liters/day (adult, 90th percentile; EPA 1989d)
1.4 liters/day (adult, average; EPA 1989d)
Age-specific values (EPA 1989d)

EF: Pathway-specific value (for residents, usually daily -- 365 days/year)

ED: 70 years (lifetime; by convention)
30 years (national upper-bound time (90th percentile) at one residence; EPA 1989d)
9 years (national median time (50th percentile) at one residence; EPA 1989d)

BW: 70 kg (adult, average; EPA 1989d)
Age-specific values (EPA 1985a, 1989d)

AT: Pathway-specific period of exposure for noncarcinogenic effects (i.e., ED x 365 days/year), and 70 year lifetime for carcinogenic effects (i.e., 70 years x 365 days/year).

[a] *See Section 6.4.1 and 6.6.1 for a discussion of which variable values should be used to calculate the reasonable maximum exposure. In general, combine 95th or 90th percentile values for contact rate and exposure frequency and duration variables.*

EXHIBIT 6-12

RESIDENTIAL EXPOSURE: INGESTION OF CHEMICALS IN SURFACE WATER WHILE SWIMMING[a]

Equation:

$$\text{Intake (mg/kg-day)} = \frac{\text{CW x IR x EF x ED}}{\text{BW x AT}}$$

Where:

CW = Chemical Concentration in Water (mg/liter)
CR = Contact Rate (liters/hour)
IR = Ingestion Rate (liters/day)
ET = Exposure Time (hours/event)
EF = Exposure Frequency (events/year)
ED = Exposure Duration (years)
BW = Body Weight (kg)
AT = Averaging time (period over which exposure is averaged -- days)

Variable Values:

CW: Site-specific measured or modeled value

CR: 50 ml/hour (EPA 1989d)

EF: Pathway-specific value

EF: Pathway-specific value (should consider local climatic conditions [e.g., number of days above a given temperature] and age of potentially exposed population)
7 days/year (national average for swimming; USDOI in EPA 1988b, EPA 1989d)

ED: 70 years (lifetime; by convention)
30 years (national upper-bound time (90th percentile) at one residence; EPA 1989d)
9 years (national median time (50th percentile) at one residence; EPA 1989d)

BW: 70 kg (adult, average; EPA 1989d)
Age-specific values (EPA 1985a, 1989d)

AT: Pathway-specific period of exposure for noncarcinogenic effects (i.e., ED x 365 days/year), and 70 year lifetime for carcinogenic effects (i.e., 70 years x 365 days/year).

[a] *See Section 6.4.1 and 6.6.1 for a discussion of which variable values should be used to calculate the reasonable maximum exposure. In general, combine 95th or 90th percentile values for contact rate and exposure frequency and duration variables.*

EXHIBIT 6-13

RESIDENTIAL EXPOSURE: DERMAL CONTACT WITH CHEMICALS IN WATER[a]

Equation:

$$\text{Absorbed dose (mg/kg-day)} = \frac{CW \times SA \times PC \times ET \times EF \times ED \times CF}{BW \times AT}$$

Where:

CW = Chemical Concentration in Water (mg/liter)
SA = Skin Surface Area Available for Contact (cm^2)
PC = Chemical-specific Dermal Permeability Constant (cm/hr)
ET = Exposure Time (hours/day)
EF = Exposure Frequency (days/year)
ED = Exposure Duration (years)
CF = Volumetric Conversion Factor for Water (1 liter/1000 cm^3)
BW = Body Weight (kg)
AT = Averaging time (period over which exposure is averaged -- days)

Variable Values:

CW: Site-specific measured or modeled value

SA:

50th Percentile Total Body Surface Area (m^2) (EPA 1989d, 1985a)

AGE (YRS)	MALE	FEMALE
3 < 6	0.728	0.711
6 < 9	0.931	0.919
9 < 12	1.16	1.16
12 < 15	1.49	1.48
15 < 18	1.75	1.60
Adult	1.94	1.69

50th Percentile Body Part-specific Surface Areas for Males (m^2) (EPA 1989d, 1985a)

AGE (YRS)	ARMS	HANDS	LEGS	
3 < 4	0.096	0.040	0.18	
6 < 7	0.11	0.041	0.24	
9 < 10	0.13	0.057	0.31	
Adult		0.23	0.082	0.55

[a] See Section 6.4.1 and 6.6.1 for a discussion of which variable values should be used to calculate the reasonable maximum exposure. In general, combine 95th or 90th percentile values for contact rate and exposure frequency and duration variables. Use 50th percentile values for SA; see text for rationale.

(continued)

EXHIBIT 6-13 (continued)

RESIDENTIAL EXPOSURE: DERMAL CONTACT WITH CHEMICALS IN WATER[a]

NOTE: ***Values for children were calculated using age-specific body areas and the average percentage of total body surface area represented by particular body parts in children, presented in EPA 1985a. Values for adults presented in EPA 1989d or calculated from information presented in EPA 1985a. Information on surface area of other body parts (e.g. head, feet) and for female children and adults also is presented in EPA 1985a, 1989d. Differences in body part surface areas between sexes is negligible.***

PC: **Consult open literature for values [Note that use of PC values results in an estimate of absorbed dose.]**

ET: **Pathway-specific value (consider local activity patterns if information is available)**
2.6 hrs/day (national average for swimming; USDOI in EPA 1988b, EPA 1989d)

EF: **Pathway-specific value (should consider local climatic conditions [e.g., number of days above a given temperature] and age of potentially exposed population)**
7 days/year (national average for swimming; USDOI in EPA 1988b, EPA 1989d)

ED: **70 years (lifetime; by convention)**
30 years (national upper-bound time (90th percentile) at one residence; EPA 1989d)
9 years (national median time (50th percentile) at one residence; EPA 1989d)

CF: **1 liter/1000 cm^3**

BW: **70 kg (adult, average; EPA 1989d)**
Age-specific values (EPA 1985a, 1989d)

AT: **Pathway-specific period of exposure for noncarcinogenic effects (i.e., ED x 365 days/year), and 70 year lifetime for carcinogenic effects (i.e., 70 years x 365 days/year).**

[a] *See Section 6.4.1 and 6.6.1 for a discussion of which variable values should be used to calculate the reasonable maximum exposure. In general, combine 95th or 90th percentile values for contact rate and exposure frequency and duration variables.*

To calculate the reasonable maximum exposure for this pathway, 50th percentile values, instead of 95th percentile values, are used for the area of exposed skin (SA). This is because surface area and body weight are strongly correlated and 50th percentile values are most representative of the surface area of individuals of average weight (e.g., 70 kg) which is assumed for this and all other exposure pathways. Estimates of exposure for this pathway are still regarded as conservative because generally conservative assumptions are used to estimate dermal absorption (PC) and exposure frequency and duration.

Consider pathway-specific variations for the intake variables. SA will vary with activity and the extent of clothing worn. For example, a greater skin surface area would be in contact with water during bathing or swimming than when wading. Worker exposure via this pathway will depend on the type of work performed at the site, protective clothing worn, and the extent of water use and contact.

6.6.2 CALCULATE SOIL, SEDIMENT, OR DUST INTAKES

Individuals may be exposed to chemicals of potential concern in soil, sediment, or dust by the following routes:

(1) incidental ingestion; and
(2) dermal contact.

Inhalation exposures to airborne soil or dust are discussed in Section 6.6.3.

Incidental ingestion. Calculate intakes from incidental ingestion of chemicals in soil by residents using the equation and variable values presented in Exhibit 6-14. Consider population characteristics that might influence variable values. Exposure duration (ED) may be less for workers and recreational users.

The value suggested for ingestion rate (IR) for children 6 years old and younger are based primarily on fecal tracer studies and account for ingestion of indoor dust as well as outdoor soil. These values should be viewed as representative of long-term average daily ingestion rates for children and should be used in conjunction with an exposure frequency of 365 days/year. A term can be used to account for the fraction of soil or dust contacted that is presumed to be contaminated (FI). In some cases, concentrations in indoor dust can be equal to those in outdoor soil. Conceivably, in these cases, FI could be equal to 1.0.

For ingestion of chemicals in sediment, use the same equation as that used for ingestion of soil. Unless more pathway-specific values can be found in the open literature, use as default variable values the same values as those used for ingestion of soil. In most instances, contact and ingestion of sediments is not a relevant pathway for industrial/commercial land use (a notable exception to this could be workers repairing docks).

Dermal contact. Calculate exposure from dermal contact with chemicals in soil by residents using the equation and variable values presented in Exhibit 6-15. As was the case with exposure to chemicals in water, calculation of exposure for this pathway results in an estimate of the absorbed dose, not the amount of chemical in contact with the skin (i.e., intake). Absorption factors (ABS) are used to reflect the desorption of the chemical from soil and the absorption of the chemical across the skin and into the blood stream. Consult the open literature for information on chemical-specific absorption factors. In the absence of chemical-specific information, use conservative assumptions to estimate ABS.

Again, as with dermal exposure to water, 50th percentile body surface area (SA) values are used to estimate contact rates. These values are used along with average body weight because of the strong correlation between surface area and body weight. Contact rates may vary with time of year and may be greater for individuals contacting soils in the warmer months of the year when less clothing is worn (and hence, more skin is available for contact). Adherence factors (AF) are available for few soil types and body parts. The literature should be reviewed to derive AF values for other soil types and other body parts. Exposure frequency (EF) is generally determined using site-specific information and professional judgment.

EXHIBIT 6-14

RESIDENTIAL EXPOSURE: INGESTION OF CHEMICALS IN SOIL[a]

Equation:

$$\text{Intake (mg/kg-day)} = \frac{CS \times IR \times CF \times FI \times EF \times ED}{BW \times AT}$$

Where:

CS = Chemical Concentration in Soil (mg/kg)
IR = Ingestion Rate (mg soil/day)
CF = Conversion Factor (10^{-6} kg/mg)
FI = Fraction Ingested from Contaminated Source (unitless)
EF = Exposure Frequency (days/year)
ED = Exposure Duration (years)
BW = Body Weight (kg)
AT = Averaging time (period over which exposure is averaged -- days)

Variable Values:

CS: Site-specific measured value

IR: 200 mg/day (children, 1 through 6 years old; EPA 1989g)
100 mg/day (age groups greater than 6 years old; EPA 1989g)

NOTE: IR values are default values and could change based on site-specific or other information. Research is currently ongoing to better define ingestion rates. IR values do not apply to individuals with abnormally high soil ingestion rates (i.e., pica).

CF: 10^{-6} kg/mg

FI: Pathway-specific value (should consider contaminant location and population activity patterns)

EF: 365 days/year

ED: 70 years (lifetime; by convention)
30 years (national upper-bound time (90th percentile) at one residence; EPA 1989d)
9 years (national median time (50th percentile) at one residence; EPA 1989d)

BW: 70 kg (adult, average; EPA 1989d)
16 kg (children 1 through 6 years old, 50th percentile; EPA 1985a)

AT: Pathway-specific period of exposure for noncarcinogenic effects (i.e., ED x 365 days/year), and 70 year lifetime for carcinogenic effects (i.e., 70 years x 365 days/year).

[a] *See Section 6.4.1 and 6.6.2 for a discussion of which variable values should be used to calculate the reasonable maximum exposure. In general, use 95th or 90th percentile values for contact rate and exposure frequency and duration variables.*

EXHIBIT 6-15

RESIDENTIAL EXPOSURE: DERMAL CONTACT WITH CHEMICALS IN SOIL[a]

Equation:

$$\text{Absorbed Dose (mg/kg-day)} = \frac{CS \times CF \times SA \times AF \times ABS \times EF \times ED}{BW \times AT}$$

Where:

CS = Chemical Concentration in Soil (mg/kg)
CF = Conversion Factor (10^{-6} kg/mg)
SA = Skin Surface Area Available for Contact (cm^2/event)
AF = Soil to Skin Adherence Factor (mg/cm^2)
ABS = Absorption Factor (unitless)
EF = Exposure Frequency (events/year)
ED = Exposure Duration (years)
BW = Body Weight (kg)
AT = Averaging Time (period over which exposure is averaged -- days)

Variable Values:

CS: Based on site-specific measured value

CF: (10^{-6} kg/mg)

SA:

50th Percentile Total Body Surface Area (m^2) (EPA 1989d, 1985a)

AGE (YRS)	MALE	FEMALE
3 < 6	0.728	0.711
6 < 9	0.931	0.919
9 < 12	1.16	1.16
12 < 15	1.49	1.48
15 < 18	1.75	1.60
Adult	1.94	1.69

50th Percentile Body Part-specific Surface Areas for Males (m^2) (EPA 1989d, 1985a)

AGE (YRS)	ARMS	HANDS	LEGS	
3 < 4	0.096	0.040	0.18	
6 < 7	0.11	0.041	0.24	
9 < 10	0.13	0.057	0.31	
Adult		0.23	0.082	0.55

NOTE: Values for children were calculated using age-specific body surface areas and the average percentage of total body surface area represented by particular body parts in children, presented in EPA 1985a. Values for adults presented in EPA 1989d or calculated from information presented in EPA 1985a.

[a] *See Section 6.4.1 and 6.6.1 for a discussion of which variable values should be used to calculate the reasonable maximum exposure. In general, combine 95th or 90th percentile values for contact rate and exposure frequency variables. Use 50th percentile values for SA; see text for rationale.*

(continued)

EXHIBIT 6-15 (continued)

RESIDENTIAL EXPOSURE: DERMAL CONTACT WITH CHEMICALS IN SOIL[a]

NOTE (continued): Information on surface area of other body parts (e.g., head, feet) and for female children and adults also is presented in EPA 1985a, 1989d. Differences in body part surface areas between sexes is negligible.

AF: 1.45 mg/cm^2 -- commercial potting soil (for hands; EPA 1989d, EPA 1988b)
2.77 mg/cm^2 -- kaolin clay (for hands; EPA 1989d, EPA 1988b)

ABS: Chemical-specific value (this value accounts for desorption of chemical from the soil matrix and absorption of chemical across the skin; generally, information to support a determination of ABS is limited – see text)

EF: Pathway-specific value (should consider local weather conditions [e.g., number of rain, snow and frost-free days] and age of potentially exposed population)

ED: 70 years (lifetime; by convention)
30 years (national upper-bound time (90th percentile) at one residence; EPA 1989d)
9 years (national median time (50th percentile) at one residence; EPA 1989d)

BW: 70 kg (adult, average; EPA 1989d)
Age-specific values (EPA 1985a, 1989d)

AT: Pathway-specific period of exposure for noncarcinogenic effects (i.e., ED x 365 days/year), and 70 year lifetime for carcinogenic effects (i.e., 70 years x 365 days/year)

[a] *See Section 6.4.1 and 6.6.1 for a discussion of which variable values should be used to calculate the reason-able maximum exposure. In general, combine 95th or 90th percentile values for contact rate and exposure frequency and duration variables.*

"Best guess" values for children potentially useful in risk assessments are 3 times/week for fall and spring days (>32°F) and 5 times/week for summer days when children are not attending school. As discussed previously, in some cases, concentrations in indoor dust could be equal to that in outdoor environments. Therefore, at some sites, EF could be 365 days/year. Worker and recreational user contact rates are dependent on the type of activity at the site. Exposure duration (ED) and exposure frequency (EF) may be lower for workers and recreational users.

For dermal contact with sediment or dust, use the same equation as that for dermal contact with soil. As default values, also use the variable values given for dermal contact with soil unless more pathway-specific values can be found in the open literature. Adherence factors for some sediments (particularly sandy sediments) are likely to be much less than for soils because contact with water may wash the sediment off the skin. Exposure frequency for sediments also is probably lower than that for soils at many sites.

6.6.3 CALCULATE AIR INTAKES

Individuals may be exposed to chemicals of potential concern in air by inhalation of chemicals in the vapor phase or adsorbed to particulates. Dermal absorption of vapor phase chemicals is considered to be lower than inhalation intakes in many instances and generally is not considered in Superfund exposure assessments.

As with other pathways, the inhalation intakes are expressed in units of mg/kg-day. The combination of inhalation intakes with inhalation RfDs (expressed in concentration units of mg/m^3) will be discussed in Chapters 7 and 8.

Inhalation of vapor-phase chemicals . Calculate intakes from inhalation of vapor phase chemicals using the equation and variable values presented in Exhibit 6-16. Consider variations with land use. Exposure time (ET) will generally be less for workers and recreational users. For exposure times less than 24 hours per day, an hourly inhalation rate (IR) based on activity, age, and sex should be used instead of the daily IR values. Exposure duration (ED) may also be less for workers and recreational users.

Inhalation of particulate phase chemicals. Calculate intakes from inhalation of particulate phase chemicals by modifying the equations and variable values presented in Exhibit 6-16 for vapor-phase exposures. Derive inhalation estimates using the particulate concentration in air, the fraction of the particulate that is respirable (i.e., particles 10 um or less in size) and the concentration of the chemical in the respirable fraction. Note that it may be necessary to adjust intakes of particulate phase chemicals if they are to be combined with toxicity values that are based on exposure to the chemical in the vapor phase. This adjustment is done in the risk characterization step.

6.6.4 CALCULATE FOOD INTAKES

Individuals may be exposed by ingestion of chemicals of potential concern that have accumulated in food. The primary food items of concern are:

(1) fish and shellfish;

(2) vegetables and other produce; and

(3) meat, eggs, and dairy products (domestic and game species).

Ingestion of fish and shellfish. Calculate intakes from ingestion of fish and shellfish using the equation and variable values given in Exhibit 6-17. Exposure will depend in part on the availability of suitable fishing areas. The chemical concentration in fish or shellfish (CF) should be the concentration in the edible tissues (when available). The edible tissues will vary with aquatic species and with population eating habits. Residents near major commercial or recreational fisheries or shell fisheries are likely to ingest larger quantities of locally caught fish and shellfish than inland residents. In most instances, workers are not likely to be exposed via this pathway, although at some sites this may be possible.

Ingestion of vegetables or other produce. Calculate intakes from ingestion of contaminated vegetables or other produce using the equation and variable values given in Exhibit 6-18. This pathway will be most significant for farmers and for rural and urban residents consuming homegrown fruits and vegetables. For contaminated backyard gardens, the fraction of food ingested that is contaminated (FI) can be estimated using information on the fraction of fruits or vegetables consumed daily that is home grown (HF). EPA (1989d) provides HF values for fruit (0.20, average; 0.30 worst-case) and vegetables (0.25, average; 0.40,

EXHIBIT 6-16

RESIDENTIAL EXPOSURE: INHALATION OF AIRBORNE (VAPOR PHASE) CHEMICALS [a] [b]

Equation:

$$\text{Intake (mg/kg-day)} = \frac{\text{CA} \times \text{IR} \times \text{ET} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}}$$

Where:

CA = Chemical Concentration in Air (mg/m^3)
IR = Inhalation Rate (m^3/hour)
ET = Exposure Time (hours/day)
EF = Exposure Frequency (days/year)
ED = Exposure Duration (years)
BW = Body Weight (kg)
AT = Averaging Time (period over which exposure is averaged – days)

Variable Values:

CA: Site-specific measured or modeled value

IR: 30 m^3/day (adult, suggested upper bound value; EPA 1989d)
20 m^3/day (adult, average; EPA 1989d)
Hourly rates (EPA 1989d)
Age-specific values (EPA 1985a)
Age, sex, and activity based values (EPA 1985a)
0.6 m^3/hr – showering (all age groups; EPA 1989d)

ET: Pathway-specific value (dependent on duration of exposure-related activities)
12 minutes – showering (90th percentile; EPA 1989d)
7 minutes – showering (50th percentile; EPA 1989d)

EF: Pathway-specific value (dependent on frequency of showering or other exposure-related activities)

ED: 70 years (lifetime; by convention)
30 years (national upper-bound time (90th percentile) at one residence; EPA 1989d)
9 years (national median time (50th percentile) at one residence; EPA 1989d)

BW: 70 kg (adult, average; EPA 1989d)
Age-specific values (EPA 1985a, 1989d)

AT: Pathway-specific period of exposure for noncarcinogenic effects (i.e., ED x 365 days/year), and 70 year lifetime for carcinogenic effects (i.e., 70 years x 365 days/year).

[a] *See Section 6.4.1 and 6.6.3 for a discussion of which variable values should be used to calculate the reasonable maximum exposure. In general, use 95th or 90th percentile values for contact rate and exposure frequency and duration variables.*

[b] *The equation and variable values for vapor phase exposure can be used with modification to calculate particulate exposure. See text.*

EXHIBIT 6-17

RESIDENTIAL EXPOSURE: FOOD PATHWAY -- INGESTION OF CONTAMINATED FISH AND SHELLFISH [a]

Equation:

$$\text{Intake (mg/kg-day)} = \frac{CF \times IR \times FI \times EF \times ED}{BW \times AT}$$

Where:

CF = Chemical Concentration in Fish (mg/kg)
IR = Ingestion Rate (kg/meal)
FI = Fraction Ingested from Contaminated Source (unitless)
EF = Exposure Frequency (meals/year)
ED = Exposure Duration (years)
BW = Body Weight (kg)
AT = Averaging time (period over which exposure is averaged – days)

Variable Values:

CF: Site-specific measured or modeled value

IR: 0.284 kg/meal (95th percentile for fin fish; Poa *et al.* 1982)
0.113 kg/meal (50th percentile for fin fish; Poa *et al.* 1982)

132 g/day (95th percentile daily intakes averaged over three days for consumers of fin fish; Poa *et al.* 1982)
38 g/day (50th percentile daily intake averaged over three days for consumers of fin fish; Poa *et al.* 1982)
6.5 g/day (daily intake averaged over a year; EPA 1989d. NOTE: Daily intake values should be used in conjunction with an exposure frequency of 365 days/year.)
Specific values for age, sex, race, region and fish species are available (EPA 1989d, 1989h)

FI: Pathway-specific value (should consider local usage patterns)

EF: Pathway-specific value (should consider local population patterns if information is available)
48 days/year (average per capita for fish and shellfish; EPA Tolerance Assessment System in EPA 1989h)

ED: 70 years (lifetime; by convention)
30 years (national upper-bound time (90th percentile) at one residence; EPA 1989d)
9 years (national median time (50th percentile) at one residence; EPA 1989d)

BW: 70 kg (adult, average; EPA 1989d)
Age-specific values (EPA 1985a, 1989d)

AT: Pathway-specific period of exposure for noncarcinogenic effects (i.e., ED x 365 days/year), and 70 year lifetime for carcinogenic effects (i.e., 70 years x 365 days/year).

[a] *See Section 6.4.1 and 6.6.4 for a discussion of which variable values should be used to calculate the reasonable maximum exposure. In general, use 95th or 90th percentile values for intake rate and exposure frequency and duration variables.*

EXHIBIT 6-18

RESIDENTIAL EXPOSURE: FOOD PATHWAY -- INGESTION OF CONTAMINATED FRUITS AND VEGETABLES [a]

Equation:

$$\text{Intake (mg/kg-day)} = \frac{CF \times IR \times FI \times EF \times ED}{BW \times AT}$$

Where:

CF = Contaminant Concentration in Food (mg/kg)
IR = Ingestion Rate (kg/meal)
FI = Fraction Ingested from Contaminated Source (unitless)
EF = Exposure Frequency (meals/year)
ED = Exposure Duration (years)
BW = Body Weight (kg)
AT = Averaging time (period over which exposure is averaged -- days)

Variable Values:

CF: Site-specific measured value or modeled value based on soil concentration and plant:soil accumulation factor or deposition factors

IR: Specific values for a wide variety of fruits and vegetables are available (Poa et al. 1982)

FI: Pathway-specific value (should consider location and size of contaminated area relative to that of residential areas, as well as anticipated usage patterns)

EF: Pathway-specific value (should consider anticipated usage patterns)

ED: 70 years (lifetime; by convention)
30 years (national upper-bound time (90th percentile) at one residence; EPA 1989d)
9 years (national median time (50th percentile) at one residence; EPA 1989d)

BW: 70 kg (adult, average; EPA 1989d)
Age-specific values (EPA 1985a, 1989d)

AT: Pathway-specific period of exposure for noncarcinogenic effects (i.e., ED x 365 days/year), and 70 year lifetime for carcinogenic effects (i.e., 70 years x 365 days/year).

[a] *See Section 6.4.1 and 6.6.4 for a discussion of which variable values should be used to calculate the reasonable maximum exposure. In general, use 95th or 90th percentile values for contact rate and exposure frequency and duration variables.*

worst-case). (Worst-case values can be used as estimates of the 95th percentile value.) Pao *et al*. (1982) provides specific values for a variety of fruits and vegetables.

Workers are not likely to be exposed via this pathway. Recreational users could be exposed from consuming wild fruits or vegetables from the site, although such exposures are likely to be negligible.

Ingestion of meat, eggs, and dairy products. Calculate intakes from ingestion of contaminated meat and dairy products using the equation and variable values given in Exhibit 6-19. Derive pathway-specific values as necessary. Rural residents may consume poultry as well as livestock and wild game that have been exposed to contaminants at the site. The fraction of food ingested daily that is contaminated (FI) can be estimated for beef and dairy products using information provided in EPA (1989d) on the fraction of these foods that is homegrown (HF). HF for beef is estimated to be 0.44 (average) and 0.75 (worst-case). HF for dairy products is estimated to be 0.40 (average) and 0.75 (worst-case). (Worst-case values can be used as estimates of the 95th percentile value.) Consider land-use variations. Workers are not likely to be exposed via this pathway. Exposure duration (ED) and exposure frequency (EF) will likely be less for recreational users (e.g., hunters).

6.7 COMBINING CHEMICAL INTAKES ACROSS PATHWAYS

As discussed previously, the RME at a site reflects the RME for a pathway as well as the RME across pathways. A given population may be exposed to a chemical from several exposure routes. For example, residents may be exposed to chemicals in ground water via ingestion of drinking water and via inhalation of chemicals that have volatilized from ground water during its use. They also could be exposed to chemicals in vapors or dust that have migrated from the site. To calculate an exposure that is a reasonable maximum across pathways, it may be necessary to combine the RME for one pathway with an estimate of more typical exposure for another pathway (see Section 8.3.1). The average variable values identified in the previous sections can be used to calculate intakes for these more typical exposures. At this point in the assessment, estimated intakes are not summed across pathways; this is addressed in the risk characterization chapter. However, the assessor should organize the results of the previous exposure analyses (including any estimates of typical exposure) by grouping all applicable exposure pathway for each exposed population. This organization will allow risks from appropriate exposures to be combined in the risk characterization chapter (see Exhibit 6-22 for a sample summary format).

6.8 EVALUATING UNCERTAINTY

The discussion of uncertainty is a very important component of the exposure assessment. Based on the sources and degree of uncertainty associated with estimates of exposure, the decision-maker will evaluate whether the exposure estimates are the maximum exposures that can be reasonably expected to occur. Section 8.4 provides a discussion of how the exposure uncertainty analysis is incorporated into the uncertainty analysis for the entire risk assessment.

The discussion of uncertainty in the exposure assessment chapter should be separated into two parts. The first part is a tabular summary of the values used to estimate exposure and the range of these values. The table should include the variables that appear in the exposure equation as well as those used to estimate exposure concentrations (e.g., model variables). A simple example of this table is shown in Exhibit 6-20. For each variable, the table should include the range of possible values, the midpoint of the range (useful values for this part are given in Exhibits 6-11 through 6-19), and the value used to estimate exposure. In addition, a brief description of the selection rationale should be included. The discussion that accompanies the table in the exposure assessment chapter should identify which variables have the greatest range and provide additional justification for the use of values that may be less certain.

EXHIBIT 6-19

RESIDENTIAL EXPOSURE: FOOD PATHWAY -- INGESTION OF CONTAMINATED MEAT, EGGS, AND DAIRY PRODUCTS [a]

Equation:

$$\text{Intake (mg/kg-day)} = \frac{CF \times IR \times FI \times EF \times ED}{BW \times AT}$$

Where:

CF = Chemical Concentration in Food (mg/kg)
IR = Ingestion Rate (kg/meal)
FI = Fraction Ingested from Contaminated Source (unitless)
EF = Exposure Frequency (meals/year)
ED = Exposure Duration (years)
BW = Body Weight (kg)
AT = Averaging time (period over which exposure is averaged -- days)

Variable Values:

CF: Site-specific measured or modeled value. Based on soil concentrations, plant (feed) accumulation factors, and feed-to-meat or feed-to-dairy product transfer coefficients

IR: 0.28 kg/meal -- beef (95th percentile; Poa *et al.* 1982)
0.112 kg/meal – beef (50th percentile; Poa *et al.* 1982)
Specific values for other meats are available (Poa *et al.* 1982)

0.150 kg/meal -- eggs (95th percentile; Poa *et al.* 1982)
0.064 kg/meal -- eggs (50th percentile; Poa *et al.* 1982)

Specific values for milk, cheese and other dairy products are available (Poa et al. 1982)

FI: Pathway-specific value (should consider location and size of contaminated area relative to that of residential areas, as well as anticipated usage patterns)

EF: Pathway-specific value (should consider anticipated usage patterns)

ED: 70 years (lifetime; by convention)
30 years (national upper-bound time (90th percentile) at one residence; EPA 1989d)
9 years (national median time (50th percentile) at one residence; EPA 1989d)

BW: 70 kg (adult, average; EPA 1989d)
Age-specific values (EPA 1985a, 1989d)

AT: Pathway-specific period of exposure for noncarcinogenic effects (i.e., ED x 365 days/year), and 70 year lifetime for carcinogenic effects (i.e., 70 years x 365 days/year).

[a] *See Section 6.4.1 and 6.6.4 for a discussion of which variable values should be used to calculate the reasonable maximum exposure. In general, use 95th or 90th percentile values for contact rate and exposure frequency and duration.*

EXHIBIT 6-20

EXAMPLE OF TABLE FORMAT FOR SUMMARIZING VALUES USED TO ESTIMATE EXPOSURE

Variable	Range	Midpoint	Value Used	Brief Rationale
PCB concentration in soil (mg/kg)	ND - 3,500	250 (arithmetic mean)		
Chronic exposure (mg/kg)			1,400	95th percentile upperbound estimate of mean concentration
Acute exposure (mg/kg)			3,500	Maximum detected concentration
Adult soil ingestion rate (mg/d)	0 - 170	17 (arithmetic mean)	100	Range based on assumptions regarding soil adherence and percent ingestion. Value used is from EPA 1989g.
Exposure frequency (days/wk)	1 - 7	3	5	Best professional judgement.
Exposure duration (years)	1 - 20	10	20	Best professional judgement.

The second part of the uncertainty discussion is to summarize the major assumptions of the exposure assessment, to discuss the uncertainty associated with each, and to describe how this uncertainty is expected to affect the estimate of exposure. Sources of uncertainty that should be addressed include 1) the monitoring data, which may or may not be representative of actual conditions at the site; 2) the exposure models, assumptions and input variables used to estimate exposure concentrations; and 3) the values of the intake variables used to calculate intakes. Each of these sources should be discussed in the summary section of the exposure assessment. A table may be useful in summarizing this information. Exhibit 6-21 presents a sample format.

A supplemental approach to uncertainty analysis is to use analytical methods (e.g., first-order uncertainty analysis) or numerical methods (e.g., Monte Carlo analysis). These methods and their limitations are described in greater detail in Section 8.4 It is recommended that these analyses be used only after approval of the EPA project manager, and then, only as a part of the uncertainty analysis (and not as a basis for the reasonable maximum exposure).

6.9 SUMMARIZING AND PRESENTING THE EXPOSURE ASSESSMENT RESULTS

At this point, the exposure assessor should summarize the results of the exposure assessment. The summary information should be presented in table format and should list the estimated chemical-specific intakes for each pathway. The pathways should be grouped by population so that risks can be combined across pathways as appropriate. The summary information should be further grouped by current and future use categories. Within these categories, subchronic and chronic daily intakes should be summarized separately. Exhibit 6-22 presents a sample format for this summary information. In addition to the summary table, provide sample calculations for each pathway, to aid in the review of the calculations.

EXHIBIT 6-21

EXAMPLE OF AN UNCERTAINTY TABLE FOR EXPOSURE ASSESSMENT

ASSUMPTION	EFFECT ON EXPOSURE [a]		
	Potential Magnitude for Over-Estimation of Exposure	Potential Magnitude for Under-Estimation of Exposure	Potential Magnitude for Over- or Under Estimation of Exposure
Environmental Sampling and Analysis			
Sufficient samples may not have been taken to characterize the media being evaluated, especially with respect to currently available soil data.			Moderate
Systematic or random errors in the chemical analyses may yield erroneous data.			Low
Fate and Transport Modeling			
Chemicals in fish will be at equilibrium with chemical concentrations in water.	Low		
Use of Gaussian dispersion model to estimate air concentrations offsite.			Low
Use of a box model to estimate air concentrations onsite.	Low		
Use of Cowherd's model to estimate vehicle emission factors.		Moderate	
Exposure Parameter Estimation			
The standard assumptions regarding body weight, period exposed, life expectancy, population characteristics, and lifestyle may not be representative of any actual exposure situation.			Moderate
The amount of media intake is assumed to be constant and representative of the exposed population.	Moderate		
Assumption of daily lifetime exposure for residents.	Moderate to High		
Use of "hot spot" soil data for upper-bound lifetime exposure	Moderate to High		

[a] *As a general guideline, assumptions marked as "low", may affect estimates of exposure by less than one order of magnitude; assumptions marked "moderate" may affect estimates of exposure by between one and two orders of magnitude; assumptions marked "high" may affect estimates of exposure by more than two orders of magnitude.*

EXHIBIT 6-22

EXAMPLE OF TABLE FORMAT FOR SUMMARIZING THE RESULTS OF THE EXPOSURE ASSESSMENT -- CURRENT LAND USE [a]

Population	Exposure Pathway	Chemical	Chronic Daily Intake (CDI) (mg/kg-day)	
			Carcinogenic Effects	Noncarcinogenic Effects
Residents	Ingestion of ground water that has migrated from the site to downgradient local wells	Benzene	0.00025	-- [b]
		Chlordane	0.00015	0.00035
		Phenol	-- [c]	0.1
		Cyanide	-- [c]	0.0003
		Nitrobenzene	-- [c]	0.0001
	Inhalation of chemicals that have volatilized from ground water during use	Benzene	0.000013	-- [b]
	Ingestion of fish that have accumulated chemicals in nearby lake	Chlordane	0.00008	0.00019
		MEK	-- [c]	0.005
		Phenol	-- [c]	0.08

[a] Similar tables should be prepared for all subchronic daily intake (SDI) estimates as well as for all CDI and SDI estimates under future land use conditions.

[b] CDI for noncarcinogenic effects not calculated for benzene because it does not have an EPA-verified chronic reference dose (as of the publication date of this manual).

[c] CDI for carcinogenic effects not calculated for chemicals not considered by EPA to be potential human carcinogens (as of the publication date of this manual).

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