Chapter 6
General Basic Planning Considerations for a Chemical Exposure Characterization Activity

There are numerous planning engagements or actions that would typically be undertaken prior to carrying out most chemical exposure investigation and/or characterization activities. This chapter catalogs and elaborates the pertinent planning considerations, foundational building blocks/elements, and general requirements that would likely assure a reasonably cost-effective implementation of a chemical exposure investigation and characterization activity—particularly in relation to environmental contamination issues/problems; this includes a general discussion of the key elements for effectual problem conceptualization/formulation, chemical fate and behavior appraisement concepts, as well as the steps typically taken to develop comprehensive work-plans in data collection activities that are often necessary to support the characterization and management of environmental contamination and related potential chemical exposure problems.

6.1 Conceptualization of Chemical Exposure Problems

Conceptualization principles are an important starting point in formulating strategies to address most chemical exposure problems, regardless of the source of origination for the chemicals of interest and anticipated impacts. In general, a conceptual evaluation model is used to facilitate a more holistic assessment of the nature and extent of a chemical release and/or exposure problem. It also identifies all known and suspected or potential contamination sources; the types of contaminants and affected media; existing and potential exposure pathways; and the known or potential receptors that might be threatened. This information is frequently summarized in pictorial or graphical form, and generally backed up by problem-specific data. The development of an adequate conceptual model is indeed a very important aspect of the technical evaluation scheme necessary for the successful completion of most environmental and chemical exposure characterization programs. The framework integrates several types of information on the

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physical and environmental setting of the specific issue on hand—which then forms a basis for human health (and related) risk assessments. The conceptual model is also relevant to the development and evaluation of corrective action or remedy programs for a variety of chemical release and exposure problems.

Overall, a conceptual exposure model (CEM) provides a structured framework for characterizing possible threats posed by potential chemical release and/or exposure problems; these frameworks are usually developed in order to clearly and systematically identify and document likely contaminant sources, migration and exposure pathways, potential receptors, and how these individual elements are inter-connected. Ultimately, the CEM aids in the organization and analysis of basic information relevant to developing likely corrective action decisions about a problem situation. Thus, the development of a comprehensive CEM is often a recommended and vital part of corrective action assessments for chemical release and/or exposure problems. Meanwhile, it is worth the mention here that, as chemical exposure characterization activities move forward, the CEM may have to be revised as necessary—and then used to direct the next iteration of possible sampling activities necessary to complete the exposure characterization efforts. The 'finalized' CEM is then used to develop realistic exposure scenarios for the specific project on hand.

6.1.1 Elements of a Conceptual Exposure Model

Conceptual models generally establish a hypothesis about possible chemical or contaminant sources, chemical fate and behavior, and possible pathways of exposure to any populations potentially at risk (Fig. 6.1). The archetypical conceptual exposure model (CEM) will usually incorporate the following types of fundamental elements:

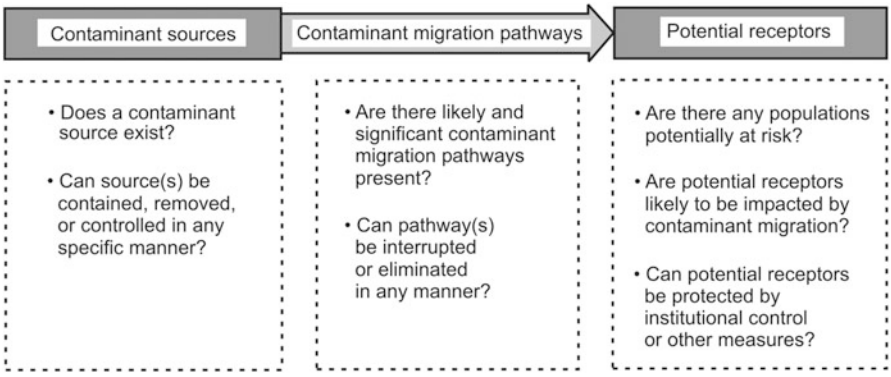

Fig. 6.1 General conceptual elements for a potential chemical exposure problem

- Identification of the contaminants of interest and determination of their physical/chemical properties
- Characterization of the source(s) of contamination and ambient conditions
- Delineation of potential migration pathways
- Identification and characterization of all populations and resources that are potentially at risk
- Determination of the nature of inter-connections between contaminant sources, contaminant migration pathways, and potential receptors.

Relationships among these elements provide a basis for testing a range of exposure hypotheses for a given chemical release and/or exposure problem.

For an archetypical environmental contamination and/or chemical exposure problem, evaluation of the CEM usually involves the following types of analyses:

- A *contaminant release analysis*—to determine contaminant release rates into specific environmental media over time. [This may include determining the spatial distribution of contaminants; appraising ambient conditions; determining the extent to which contaminant sources can be adequately identified and characterized; determining the likelihood of releases and/or exposures if the contaminants remain in-place; determining the extent to which natural and artificial barriers currently contain contaminants, and the adequacy of such barriers; identifying potential migration pathways; determining the extent to which the contaminants of interest have migrated or are expected to migrate from their source(s); and estimating the contaminant release rates into specific environmental media over time.]
- A *contaminant transport and fate analysis*—to provide guidance for evaluating the transport, transformation, and fate of contaminants in the environment following their release; to identify outside areas affected by contaminant migration; and to determine contaminant concentrations in these areas.
- An *exposed population analysis*—to determine the likelihood of human and ecological receptors coming into contact with the contaminants of concern.
- An *integrated exposure analysis*—to provide guidance for calculating and integrating exposures to all populations affected by the various exposure scenarios associated with the problem situation.

When all is said and done, the conceptual model helps to identify and document all known and suspected sources of contamination, types of contaminants and affected media, known and potential migration pathways, potential exposure pathways and routes, target receiving media, and known or potential human (and possibly ecological) receptors. Such information can be used to develop a conceptual understanding of the chemical release and/or exposure problem, so that potential risks to human health and the environment can be evaluated more completely. Eventually, the CEM will usually help identify data gaps, and further assist in developing strategies for data collection in support of public health risk management programs.

6.1.2 *Design of Conceptual Exposure Models and the Development of Exposure Scenarios*

Several considerations and evaluations are essential to the design of a realistic and truly representative CEM that will meet the overall goals of a risk assessment and environmental management program. Oftentimes, problem case history and preliminary assessment data become very useful sources of information for developing preliminary CEMs; subsequently, the CEM should be appropriately modified if the acquisition of additional data and new information necessitates a re-design. In fact, the CEM is typically prepared early on in the project, and then used to guide exposure investigations and pertinent decision-making; however, this CEM may have to be updated periodically whenever new information becomes available to elucidate a further understanding of the particular exposure problem. In the end, the complexity and degree of sophistication of a CEM usually is consistent with the complexity of the particular problem, and also the amount of data available.

6.1.2.1 Development of Exposure Scenarios: Integrating Contaminant Sources with Exposure Pathways and Receptors

An exposure scenario, which is a description of the activity that brings a population into contact with a chemical source or a contaminated environmental medium, usually is the next logical development or outcome that follows after the design of a CEM. Exposure scenarios are developed based on the movement of chemicals or contaminants of interest in various environmental compartments into the potential receptor zones (Fig. 6.2). In general, exposure scenarios are derived and modeled based on the movement of chemicals in various environmental compartments. The exposure scenario associated with a given chemical exposure problem may be well-defined if the exposure is known to have already occurred. In most cases associated with the investigation of potential chemical exposure problems, however, decisions typically have to be made about potential exposures that may not yet have occurred. Consequently, hypothetical exposure scenarios are generally developed for such applications.

Several tasks are usually undertaken to facilitate the development of complete and realistic exposure scenarios; the critical tasks include the following:

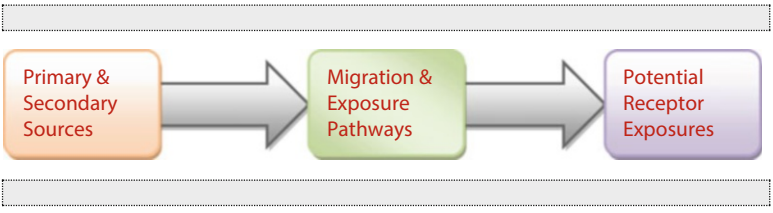

Fig. 6.2 Exposure scenario evaluation flow-diagram

- Determine the sources of chemical release or contamination
- Identify the specific constituents of concern
- Identify the affected environmental media
- Delineate contaminant migration pathways
- Identify potential receptors
- Determine potential exposure routes
- Construct a representative conceptual model for the specific problem situation
- Delineate likely and significant migration and exposure pathways.

Indeed, it is quite important to develop as realistic an exposure scenario as possible at all times; this can then be used to support an evaluation of the risks posed by the potential chemical exposure problem. Once the complete set of potential exposure scenarios have been fully determined, the range of critical exposure pathways can be identified. This information can then be used to design cost-effective sampling and investigation programs. The goal in this case will be to ensure a focused investigation, in order to be able to determine the specific potential exposure pathways of critical interest in a most cost-efficient manner. Ultimately, the exposure scenarios developed for a given chemical release and/or exposure problem can be used to support an evaluation of the risks posed by the subject case, as well as facilitate the implementation of appropriate decisions regarding the need for, and extent of, possible corrective actions to undertake.

Finally, it is noteworthy here that if numerous potential exposure scenarios exist, or if a complex exposure scenario has to be evaluated, it usually is helpful to use an 'event-tree' model (or similar framework/structure) to clarify potential outcomes and/or consequences. The event tree concept, as illustrated by Fig. 6.3, indeed offers an efficient way to develop exposure scenarios. By using such an approach, the

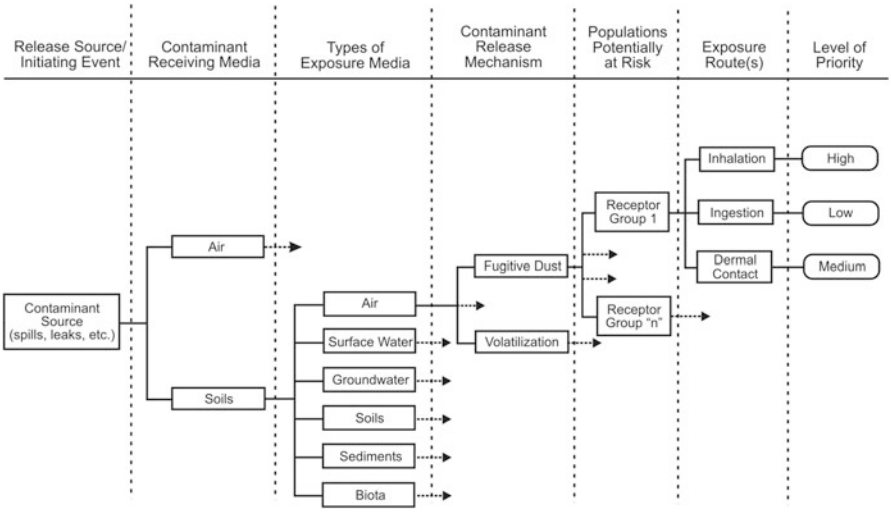

Fig. 6.3 Diagrammatic representation of example exposure scenarios using an 'event-tree'

various exposure contingencies can be identified and organized in a systematic manner. Once developed, priorities can be established to help focus the available effort on the aspects of greatest need. Invariably, a wide variety of *potential* exposure patterns may generally be anticipated from a given chemical exposure situation—culminating in a multiplicity of inter-connected pathways through which populations might become exposed to contamination. In the final analysis, the archetypal and commonly encountered exposure scenarios will usually be evaluated as part of the exposure characterization process for a given chemical exposure problem.

6.2 Fate and Behavior Appraisal for Chemicals of Potential Public Health Concern in Human Environments

A variety of chemicals originating from varying sources that are often encountered in human environments tend to be controlled by a complex set of processes—consisting of transport, transformation, degradation and decay, cross-media transfers, and/or biological uptake and bioaccumulation. Environmental fate and behavior analyses offer a way to assess the movement of chemicals between environmental compartments—further to the prediction of the long-term fate of such chemicals in the environment vis-à-vis potential human exposures. In fact, once a chemical is suspected or determined to present a potential health or environmental hazard, then the first concern relates to the likelihood for, and degree of, exposure.

This section identifies and discusses the relevant phenomena influencing the fate and behavior of chemicals encountered in human environments, together with the important factors affecting the processes involved. Indeed, a good understanding of the chemical fate and behavior is quite important—in order to be able to properly characterize the potential risks associated with chemicals encountered in human exposure environments, and to further develop appropriate risk management and/or remedial action plans for a chemical exposure problem. Thus, the processes and phenomena that affect the fate and behavior of chemicals encountered in human environments should be recognized as an important part of any chemical exposure characterization, risk determination, and/or risk management program.

6.2.1 Important Characteristics, Properties and Parameters Affecting the Destiny of Chemical Substances in Human Environments

As chemical substances are released into various environmental media, several factors contribute to their uptake, transformation, and migration/transport from one environmental matrix into another, or their phase change from one physical state into another. In general, examination of a chemical substance's physical and

chemical properties will often allow an estimation of its degree of environmental partitioning, migration and/or attenuation. Qualitative analysis of the fate of a chemical can also be made by analogy with other chemicals whose fate are well documented; that is, if the chemical under investigation is structurally similar to a previously well-studied one, some parallel can be drawn to the environmental fate of the analogue. In addition, several locale-specific characteristics—such as the amount of ambient moisture, humidity levels, temperatures and wind speed—may influence the environmental fate and behavior of chemicals. Other factors such as initial chemical concentration in the source or secondarily impacted media, as well as media pH may additionally affect the release of a chemical constituent from the environmental matrix in which it is found.

Overall, the physical and chemical characteristics of constituents present in human environments determine the fate and behavior properties of the chemical substances, and thus their degree of uptake, transformation, and/or migration through the environment. Some of the particularly important constituent properties affecting the fate and behavior of chemical substances in the human environment include the following (Grisham 1986):

- Solubility in water (which, for instance, relates to leaching, partitioning, and mobility in the environment).
- Partitioning coefficients (relating to cross-media transfers, bioaccumulation potential and sorption by organic matter).
- Hydrolysis (which relates to persistence in the environment or biota).
- Vapor pressure and Henry's Law constant (relating to atmospheric mobility and the rate of vaporization or volatilization).
- Photolysis (which relates to persistence as a function of exposure to light).
- Degradation/Half-life (relating to the degradation of contaminants and the resulting transformation products).
- Retardation factor (which relates to the sorptivity and mobility of the constituent within the solid-fluid media).

Further details and additional parameters of possible interest are presented in Appendix B of this book—with this topic receiving even more elaboration elsewhere in the literature (e.g., Devinny et al. 1990; Evans 1989; Hemond and Fechner 1994; Lindsay 1979; Lyman et al. 1990; Mahmood and Sims 1986; Mansour 1993; Neely 1980; Samiullah 1990; Swann and Eschenroeder 1983; Thibodeaux 1979, 1996; USEPA 1985a, 1989a, b, c, d, e, f; Yong et al. 1992).

6.2.2 Modeling Chemical Fate and Behavior in Human Environments

Environmental contamination can be transported far away from its primary source (s) of origination via a variety of natural and related processes—culminating in the

possible birth of secondary contaminant source and potential exposure problems. Conversely, some natural processes work to lessen or reduce contaminant concentrations in the environment through mechanisms of natural attenuation (such as dispersion/dilution, sorption and retardation, photolysis, and biodegradation). In the end, chemical contaminants entering the environment tend to be partitioned or distributed across various environmental compartments. Consequently, a good prediction of contaminant concentrations in the various environmental media is essential to adequately characterize environmental contamination and chemical exposure problems—the results of which can also be used to support risk assessment and/or risk management decisions. Typically, environmental fate and transport analysis and modeling is used to assess the movement of chemicals between environmental compartments. For instance, simple mathematical models can be used to guide the decisions involved in estimating and managing the potential spread of contaminant plumes; on the basis of the modeling results, and as appropriate or necessary, monitoring equipment or systems can then be located in areas expected to have elevated contaminant concentrations and/or in areas considered upgradient (or upwind), cross-gradient, and downgradient (or downwind) of a contaminant plume.

Mathematical algorithms are typically used to predict the potential for contaminants to migrate from one environmental media into another—or more importantly, from an environmental compartment into potential receptor locations or environmental compliance boundaries. For example, relevant exposure point concentrations associated with a contaminated land problem can be determined once the potentially affected populations are identified and the exposure scenarios are defined. Indeed, if the transport of compounds associated with this situation is considered to be under steady-state conditions, then monitoring data are generally adequate to determine potential exposure concentrations. On the other hand, if there are no data available, or if conditions are transient (such as pertains to a migrating plume in groundwater), then models are best used to predict exposure concentrations. Meanwhile, many factors—including the fate and transport properties of the chemicals of concern—must be carefully considered in the model selection process. [By the way, it is noteworthy that, for this type of problem (and in lieu of an established trend in historical data that indicates the contrary), a potentially contaminated land problem may be considered to be in steady-state with its surroundings.]

On the whole, mathematical models often serve as valuable tools for evaluating the behavior and fate of chemical constituents in various environmental media. The transport and fate of contaminants can be predicted through the use of various methods—ranging from simple mass-balance and analytical procedures to multidimensional numerical solution of coupled differential equations. Regardless, it is worth mentioning here that, due to the heterogeneity in environmental compartments and natural systems, models used for exposure assessments should be adequately tested, and insofar as possible, sensitivity runs should perhaps be carried out to help determine the most sensitive and/or critical parameters considered in the evaluation. Further discussions pertaining to the utility of wide-ranging

environmental models—including model selection criteria and limitations—can be found elsewhere in the literature of environmental and exposure modeling (e.g., CCME 1994; CDHS 1986; Clark 1996; Feenstra et al. 1991; Ghadiri and Rose 1992; Gordon 1985; Haith 1980; Honeycutt and Schabacker 1994; Johnson and Ettinger 1991; Jury et al. 1984; Mulkey 1984; NRC 1989a, b; Schnoor 1996; USEPA 1985b, 1987, 1988a, b; Williams et al. 1996). Finally, it must be emphasized here that, the effective use of models in contaminant fate and behavior assessment depends greatly on the selection of models most suitable for this purpose.

6.2.2.1 Model Selection

Numerous model classification systems with different complexities exist in practice—broadly categorized as analytical or numerical models, depending on the degree of mathematical sophistication involved in their formulation. Analytical models are models with simplifying underlying assumptions, often sufficient and appropriate for well-defined systems for which extensive data are available, and/or for which the limiting assumptions are valid. Whereas analytical models may suffice for some evaluation scenarios, numerical models (with more stringent underlying assumptions) may be required for more complex configurations and complicated systems. In any event, the choice of a model type that could be best used for specific applications is subject to numerous, sometimes convoluted, factors/constraints. Thus, simply choosing a more complicated model over a simple one will not necessarily ensure a better solution in all situations. In fact, since a model is a mathematical representation of a complex system, some degree of mathematical simplification usually must be made about the system being modeled. In these efforts, data limitations must be weighted appropriately, since it usually is not possible to obtain all of the input parameters due to the complexity (e.g., anisotropy and non-homogeneity) of natural systems.

Now, as a general word of caution, it is notable that the appropriateness of a particular model necessary to address environmental issues depends on the characteristics of the particular problem on hand; thus, the screening of models should be carefully tied to the project goals. Indeed, the wrong choice of models could result in the generation of false information—with consequential negative impacts on any decisions made thereof. On the other hand, the choice of appropriate fate and transport models that will give reasonable indications of the contaminant behavior will help produce a realistic conceptual representation of the problem—and this is important to the adequate characterization of any environmental contamination and chemical exposure problem, which in turn is a pre-requisite to developing reliable risk management policies and case-specific remedy strategies.

On the whole, the decisions about model selection can be a tricky one—often necessitating cautious warnings; this concern is best illustrated and summarized by the following interesting observation and note of comparison with 'social models' made by Kaplan (Kaplan 1964—as cited in Aris 1994), that: "Models are

undeniably beautiful, and a man may justly be proud to be seen in their company. But they may have their hidden vices. The question is, after all, not only whether they are good to look at, but whether we can live happily with them." This illustrative and somehow analogous view held by much of society about 'social models' does indeed compare very well with the underlying principles in the selection and use of environmental models—thus calling for the careful choice of such models to support chemical release and environmental management programs. Most importantly, it should be recognized that a given mathematical model that performs extremely well under one set of circumstances might not necessarily be appropriate for other similar or comparable situations for a variety of reasons.

In the end, the type of model selected to address any particular concern will be dependent on the overall goal of the assessment, the complexity of the problem, the type of contaminants of concern, the nature of the impacted and threatened media that are being considered in the investigation, and the type of corrective actions being considered. At any rate, it is noteworthy that in several environmental assessment situations, a 'ballpark' or 'order-of-magnitude' (i.e., a rough approximation) estimate of effectiveness for the contaminant behavior and fate is usually all that is required for most analyses—and in which case simple analytical models usually will suffice. General guidance for the effective selection of models in chemical release characterization and risk management decisions is provided in the literature elsewhere (e.g., CCME 1994; CDHS 1990; Clark 1996; Cowherd et al. 1985; DOE 1987; NRC 1989a, b; Schnoor 1996; USEPA 1985, 1987, 1988a, b; Walton 1984; Yong et al. 1992; Zirschy and Harris 1986).

6.2.3 Application of Mathematical Models

Models can be used to address a wide range of questions that may need to be answered in environmental contamination and chemical exposure problems, as well as their associated environmental management programs—such as in helping answer the following types of questions:

- What are the prevailing and future chemical release or contamination levels?
- Are modeling predictions of pollution or chemical release from a process or situation met in reality?
- How do pollutants or chemical releases behave in the environment?
- What is the response of the environment to receiving pollution or chemical releases?

One of the major benefits associated with the use of mathematical models in environmental and chemical release management programs relate to the fact that, environmental concentrations useful for exposure assessment and risk characterization can be estimated for several locations and time-periods of interest. Indeed, since field data frequently are limited and insufficient for accurately and completely characterizing environmental contamination and chemical exposure problems,

models can be particularly useful for studying spatial and temporal variability, together with potential uncertainties. In addition, sensitivity analyses can be performed—by varying specific parameters and then using models to explore the ramifications (as reflected by changes in the model outputs).

Models can indeed be used for several purposes in the study of environmental contamination and chemical exposure problems. More generally, mathematical models are often used to simulate the response of a simplified version of a complex system. As such, their results are imperfect. Nonetheless, when used in a technically responsible manner, they can provide a very useful basis for making technically sound decisions about an environmental contamination and/or chemical exposure problem. In fact, they are particularly useful where several alternative scenarios are to be compared. In such cases, all the alternatives are compared on a similar basis; thus, whereas the numerical results of any single alternative may not be exact, the comparative results indicating that one alternative is superior to others will usually be valid. Ultimately, the effective use of models in chemical release characterization and risk management programs depends greatly on the selection of models most suitable for its specified purpose.

Overall, the fate of chemical compounds released into the environment forms an important basis for evaluating the exposure of biological receptors to hazardous chemicals—because, once contaminants are released into the environment, the pollutants may be transported into various media and environmental matrices occupied by the receptors. For instance, releases from potential contamination sources can cause human exposures to contaminants in a variety of ways, such as the following:

- Direct inhalation of airborne vapors and also respirable particulates
- Deposition of airborne contaminants onto soils, leading to human exposure via dermal absorption or ingestion
- Ingestion of food products that have been contaminated as a result of deposition onto crops or pasture lands, and introduction into the human food chain
- Ingestion of contaminated dairy and meat products from animals consuming contaminated crops or waters
- Deposition of airborne contaminants on waterways, uptake through aquatic organisms, and eventual human consumption
- Leaching and runoff into water resources, and consequential human exposures to contaminated waters.

Mathematical models tend to play prominent roles in the evaluation of the above types of exposures. Multimedia transport models are generally employed in the prediction of the long-term fate of the chemicals in the environment. In fact, a variety of mathematical algorithms and models are commonly employed to support the determination of contaminant fate and transport in the environment—and which results are then used in estimating the consequential exposures and risks to potential receptors.

6.2.3.1 Scope of Application of Chemical Fate and Behavior Modeling for Exposure Analyses

Regardless of how much environmental and/or exposure monitoring data is available, it is almost always desirable to generate one or more of the following attributes (Schnoor 1996):

(i) An estimate of chemical concentrations under different sets of conditions;
(ii) Results for a future chemical loading scenario;
(iii) A predicted 'hindcast' or reconstructed history of chemical releases; and/or
(iv) Estimates at alternate [receptor or compliance] locations where field data do not exist.

Under such circumstances, environmental models usually come in quite handy. Characteristically, multimedia mathematical models are often used to predict the potential for contaminant migration from a chemical release source to potential receptors, using pathways analyses concepts.

The general types of modeling practices used in exposure assessments for archetypical environmental chemical release scenarios commonly consist of a use of atmospheric, surface water, groundwater, multimedia, and food-chain models. In their practical applications, several modeling scenarios will typically be simulated and evaluated using the appropriate models for a given environmental contamination or chemical release problem. For example, the study of a contaminated land problem may require the modeling of infiltration of rain water, erosion/surface runoff release of chemicals, emission of particulate matter and vapors, chemical fate and transport through the unsaturated zone, chemical transport through the aquifer system, and/or mixing of ground water with surface water—among other things (Fig. 6.4).

All in all, environmental models are typically designed to serve a variety of purposes—most importantly the following (Schnoor 1996):

- To gain better understanding of the fate and transport of chemicals existing in, or to be introduced into, the environment.
- To determine the temporal and spatial distributions of chemical exposure concentrations at potential receptor locations.
- To predict future consequences of exposure under various chemical loading or release conditions, exposure scenarios, and/or management action alternatives.
- To perform sensitivity analyses, by varying specific parameters, and then using models to explore the ramifications of such actions (as reflected by changes in the model outputs).

Ultimately, populations potentially at risk are designated, and then concentrations of the chemicals of concern are delineated or determined in each medium to which potential receptors may be exposed. Then, using the appropriate case-specific exposure parameter values, the intakes of the chemicals of concern can be estimated (see Chap. 9). Indeed, such evaluations could be about past or current

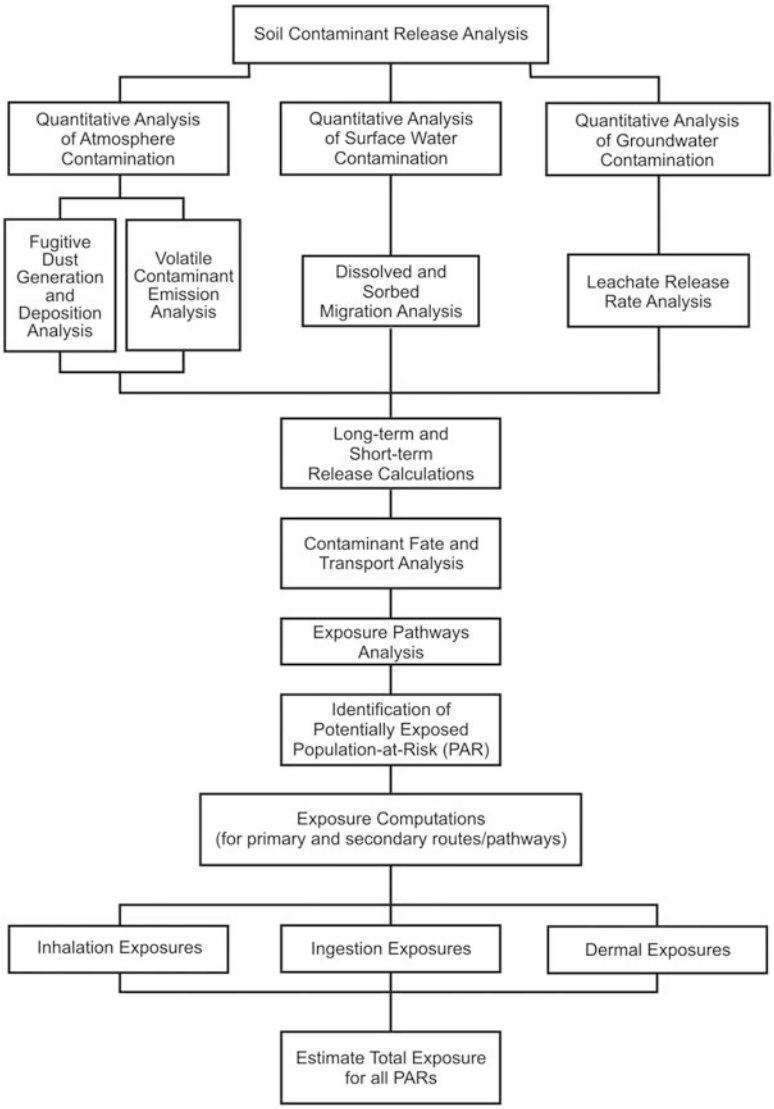

Fig. 6.4 An example conceptual representation of the relationship between multimedia contaminant transfers and multipathway exposure analyses

exposures, or exposures anticipated in the future; this therefore makes mathematical modeling even more valuable—especially in the simulation of events and conditions that may not yet have occurred.

6.2.3.2 Illustrative Example Application Scenarios for Simple Mathematical Models: The Case of Air Dispersion Modeling for Environmental Chemicals

Some simple example model formulations that may be employed in the estimation of the cross-media contaminant concentrations, and the requisite exposure point concentrations (that can be further used to facilitate responsible risk determinations) are presented below for the air migration pathway.

Atmospheric dispersion modeling has indeed become an integral part of the planning and decision-making process in the assessment of public health and environmental impacts from various chemical release problems. It is an approach that can be used to provide contaminant concentrations at potential receptor locations of interest based on emission rate and meteorological data. Naturally, the accuracy of the model predictions depends on the accuracy and representativeness of relevant input data. Broadly speaking, key model input data will include emissions and release parameters, meteorological data, and receptor locations. Typically, existing air monitoring data (if any) for the locale/area of interest can be utilized to facilitate the design of a receptor grid, as well as to select 'indicator chemicals' to be modeled. This can also provide insight into likely background concentrations. Indeed, in all situations, case-specific data should be used whenever possible—in order to increase the accuracy of the emission rate estimates.

Overall, a number of general assumptions are normally made in the assessment of contaminant releases into the atmosphere, including the following key ones:

- Air dispersion and particulate deposition modeling of emissions adequately represent the fate and transport of chemical emission to ground level.
- The composition of emission products found at ground level is identical to the composition found at source, but concentrations are different.
- The potential receptors are exposed to the maximum annual average ground-level concentrations from the emission sources for 24 h/day, throughout a 70-year lifetime—a rather conservative assumption.
- There are no losses of chemicals through transformation and other processes (such as biodegradation or photodegradation)—a rather conservative assumption.

In the end, the combined approach of environmental fate analysis and field monitoring should provide an efficient and cost-effective strategy for investigating the impacts of air pathways on potential receptors, given a variety of meteorological conditions.

Some select screening level air emission modeling procedures are discussed below for illustrative purposes only; these include the archetypical computational procedures for both volatile and non-volatile emissions—with the non-volatile compounds generally considered to be bound onto particulates by adsorption. [By the way, for the purposes of a screening evaluation, a volatile substance may be defined as any chemical with a vapor pressure greater than $[1 \times 10^{-3}]$ mmHg or

a Henry's Law constant greater than [1×10^{-5}] atm-m^3/mole (DTSC 1994). Thus, chemicals with Henry's Law constants less than or equal to these indicated values are generally considered as non-volatile compounds.] General and specific protocols for estimating releases or emission levels for contaminants from several sources are available elsewhere in the literature (e.g., CAPCOA 1990; CDHS 1986; Mackay and Leinonen 1975; Mackay and Yeun 1983; Thibodeaux and Hwang 1982; USEPA 1989a, b, 1989c, 1990a, b).

Screening Level Estimation of Airborne Dust/Particulate Concentrations: Particulate emissions from chemical release sources (e.g., potentially contaminated sites) can cause human exposures to chemical constituents in a variety of ways, including:

- Direct inhalation of respirable particulates
- Deposition on soils, leading to human exposure via dermal absorption or ingestion
- Ingestion of food products that have been contaminated as a result of deposition on crops or pasture lands and introduction into the human food chain
- Ingestion of contaminated dairy and meat products from animals eating contaminated crops
- Deposition on waterways, uptake through aquatic organisms, and eventual human consumption.

In the estimation of potential risks from particulate matter or fugitive dust inhalation, an estimate of respirable (oftentimes assumed to be <10 μm aerodynamic diameter, denoted by the symbol PM-10 or PM10) fraction and concentrations are required. The amount of non-respirable (>10 μm aerodynamic diameter) concentrations may also be needed to estimate deposition of wind-blown emissions which will eventually reach potential receptors via other routes such as ingestion and dermal exposures.

In general, air models for fugitive dust emission and dispersion can be used to estimate the applicable exposure point concentrations of respirable particulates from chemical release sources, such as contaminated lands. In such models, fugitive dust dispersion concentrations evaluated are typically represented by a three-dimensional Gaussian distribution of particulate emissions from the source (e.g., CAPCOA 1989; CDHS 1986; DOE 1987; USEPA 1989a, b, c, d, e, f; USEPA 1993). Oftentimes, a screening level assumption is made that, for non-VOCs, particulate contamination levels are directly proportional to the maximum soil concentrations.

Screening Level Estimation of Airborne Vapor Concentrations: The most important chemical parameters to consider in the evaluation of volatile air emissions are the vapor pressure and the Henry's Law Constant. Vapor pressure is a useful screening indicator of the potential for a chemical to volatilize from the media in which it currently exists. As a special example in relation to the utility of the Henry's Law Constant, it is notable that this is particularly important in estimating the tendency of a chemical to volatilize from a surface impoundment or water; it also indicates

the tendency of a chemical to, for example, partition between the soil and gas phase from soil water in the vadose zone or groundwater at a contaminated land. As an example in regards to the evaluation of a contaminated site problem, a vaporization model may be used to calculate flux from volatile compounds present in soils into the overlying air zone (DTSC 1994; USEPA 1990a, b, 1992a, b, c, d, e). Ultimately, the potential air contaminant concentration in the receptor's breathing zone that results from volatilization of chemicals through the soil surface is calculated over each discrete area of concern. A simple box model (e.g., Hwang and Falco 1986; USEPA 1990a, b, 1992a, b, c, d, e) can be used to provide an estimate of ambient air concentrations using a prior-calculated total emission rate; in this case, the length dimensions of the hypothetical box within which mixing will occur is usually based on the minimum dimensions of a residential lot in the applicable locality/region (Hadley and Sedman 1990).

6.3 The Chemical Exposure Characterization Process: General Framework for Project/Field Data Collection

As part of any potential chemical exposure characterization and/or corrective action assessment program designed to address potential chemical release and consequential exposure problems, a carefully executed investigative strategy or 'work-plan' may be developed to guide all relevant activities or decisions. Work-plans are generally required to specify the administrative and logistic requirements of potential chemical exposure investigation/characterization activities. A typical work-plan developed to facilitate the investigation of potential chemical release and related exposure problems will usually consist of the following key components:

- A sampling and analysis plan;
- A health and safety plan;
- An investigation-generated waste management plan;
- A project/program activity plan; and
- A quality assurance/quality control plan.

All the workplan elements, as represented by the summary listing in Box 6.1, should be adequately evaluated and appropriately documented. The major components and tasks required of most potential chemical exposure characterization and/or the corrective action evaluation workplans are elaborated further in the proceeding sections—with greater details offered elsewhere in the literature (e.g., Boulding 1994; CCME 1993; CDHS 1990; Keith 1988, 1991; USEPA 1985, 1987, 1988a, b, 1989a, b, c, d).

Box 6.1 General elements of a typical environmental or chemical exposure investigation/characterization work-plan

- Identification of general impacted subject(s), region or locale
- Number of individuals to be involved in each field sampling task and estimated duration of work
- Identification of sampling locations (preferably on a map to be provided in a detailed workplan)
- Number of samples to be obtained in the field (including blanks and duplicates), and the sampling location (illustrated on maps to be included in a detailed workplan)
- An elaboration of how investigation-generated wastes will be handled
- List of field and laboratory analyses to be performed
- A general discussion of data quality objectives (DQOs)
- Identification of possible interim remedies, as necessary, and/or risk management strategies
- A discussion of health and safety plans required for the investigation or corrective action activities, as well as that necessary to protect populations in the general vicinity of the impacted region or locale

6.3.1 The Sampling and Analysis Plan

Some form of a sampling and analysis plan (SAP) is an essential requirement of just about any environmental investigation/characterization program. SAPs generally are required to specify sample types, numbers, locations, and relevant procedures or strategies. In fact, the SAP typically will set the stage for developing cost-effective and effectual corrective action or remedy plans for potential environmental contamination and/or chemical exposure problems. Its purpose is to ensure that sampling and data collection activities will be comparable to, and compatible with previous (and possible future) data collection activities. Box 6.2 enumerates a checklist of the specific kinds of items that need to be ascertained in the development of a typical SAP (CCME 1993; Holmes et al. 1993; Keith 1988, 1991).

Box 6.2 Checklist for developing sampling and analysis protocols

- What observations at sampling locations are to be recorded?
- Has information concerning data quality objectives, analytical methods, analytical detection limits, etc., been included?
- Have instructions for modifying protocols in case of unanticipated problems been specified?
- Has a list of all likely sampling equipment and materials been prepared?

(continued)

Box 6.2 (continued)

- Are instructions for cleaning equipment before and after sampling available?
- Has instructions for each type of sample collection been prepared?
- Has instructions for completing sample labels been included?
- Has instructions for preserving each type of sample (such as preservatives to use, and also maximum holding times of samples) been included?
- Has instructions for packaging, transporting, and storing samples been included?
- Has instructions for chain-of-custody procedures been included?
- Has health and safety plans been developed?
- Is there a waste management plan to deal with wastes generated during the environmental impact investigation activities?

Overall, SAPs provide a mechanism for planning and approving field activities (USEPA 1988a, b, 1989b). Data necessary to meet the project objectives should be specified, including the selection of sampling methods and analytical protocols for the particular situation or project; this will also include an evaluation of multiple-option approaches that will ensure timely and cost-effective data collection and evaluation. The required level of detail and the scope of the planned investigation generally determine the 'data quality objectives' (DQOs)—with the DQOs setting the goals and requirements necessary for acquiring the appropriate data that satisfies the overarching needs of the project on hand. In any event, it is important that the sampling and analysis strategy is planned in such a manner as to minimize the costs associated with achieving the DQOs.

Typically, the SAP will comprise of two major components—namely (USEPA 1988a, b, 1989b):

1. A *quality assurance project plan* (QAPP)—that describes the policy, organization, functional activities, and quality assurance and quality control protocols necessary to achieve the DQOs dictated by the intended use of the data.
2. A *field sampling plan* (FSP)—that provides guidance for all fieldwork, by defining in detail the sampling and data-gathering methods to be used in a project. The FSP should be written so that even a field sampling team unfamiliar with the project is still able to gather the samples and any field information required for the project.

In general, the design of a sampling and analysis program and its associated quality assurance plan takes account of the variability in the entire measurement process along with the sources and magnitude of the variation in the results generated. It also provides a means of determining whether a sampling and analysis program meets the specified DQOs. Ultimately, effective protocols are required in

the sampling and laboratory procedures, in order to help minimize uncertainties in the environmental investigation process.

On the whole, the methods by which data of adequate quality and quantity are to be obtained to meet the overall project goals should be specified and fully documented in the SAP developed as part of a detailed environmental investigation work-plan. Among other things, an initial evaluation of a chemical release and consequential potential exposure problem should provide some insight into the types of contaminants, the populations potentially at risk, and possibly an approximation of the magnitude of the risk. These factors can then be combined to design a sampling plan, and to specify the size of sampling units to be addressed by each sample or set of samples. Also, it is notable that, in a number of situations, the laboratory designated to perform the sample analyses provides sample bottles, preservation materials, and explicit sample collection instructions; this is in part because of the complexity of typically having to gather so many different samples from various matrices that may also have to be analyzed using a wide range of analytical protocols.

In the end, the methods by which data of adequate quality and quantity are to be obtained to meet the overall project goals should be specified and fully documented in the SAP that is developed as part of a detailed environmental characterization work-plan. Meanwhile, it should also be recognized that the selection of analytical methods is an integral part of the processes involved in the development of sampling plans, since this can strongly affect the acceptability of a sampling protocol. Furthermore, the use of appropriate sample collection methods can be as important as the use of appropriate analytical methods for sample analyses—and vice versa.

6.3.1.1 Purpose of the Sampling and Analysis Program

Sampling and analysis of environmental pollutants is a very important part of the decision-making process involved in the management of potential chemical exposure and environmental contamination problems. Yet, sampling and analysis could become one of the most expensive and time-consuming aspects of an environmental management or potential chemical exposure characterization project. Even of greater concern is the fact that errors in sample collection, sample handling, or laboratory analysis can invalidate potential chemical exposure characterization projects or add to the overall project costs. As such, all environmental samples that are intended for use in potential chemical exposure characterization programs must be collected, handled, and analyzed properly, in accordance with all applicable/relevant methods and protocols.

The principal objective of a sampling and analysis program is to obtain a small and informative portion of the statistical population being investigated, so that chemical or contaminant levels can be established as part of a potential chemical exposure characterization and/or corrective action assessment program. Box 6.3 provides a convenient checklist of the issues that should be verified when planning

a sampling activity for a potential chemical exposure problem, in order that the project goals are attained.

Box 6.3 Sampling plan checklist

- What are the DQOs, and what corrective measures are planned if DQOs are not met (e.g., re-sampling or revision of DQOs)?
- Do program objectives need exploratory, monitoring, or both sampling types?
- Is specialized sampling equipment needed and/or available?
- Are field crew who are experienced in the required types of sampling available?
- Have all analytes and analytical methods been listed?
- Have required good laboratory practice and/or method QA/QC protocols been listed?
- What type of sampling approach will be used (i.e., random, systematic, judgmental, or combinations thereof)?
- What type of data analysis methods will be used (e.g., geostatistical, control charts, hypothesis testing, etc.)?
- Is the sampling approach compatible with data analysis methods?
- How many samples are needed?
- What types of QC samples are needed, and how many of each type of QC samples are needed (e.g., trip blanks, field blanks, equipment blanks, etc.)?

6.3.1.2 Elements of a Sampling and Analysis Plan: Sampling Requirements and Considerations

Environmental sampling activities associated with potential chemical exposure problems are generally carried out in order to help characterize the issue on hand via a risk determination process, and subsequently to facilitate any necessary corrective actions. Several project-specific requirements are important to achieving the requisite problem characterization goals. Indeed, several important issues come into play when one is making a decision on how to obtain reliable samples; these include considerations of the sampling objective and approach, sample collection methods, chain-of-custody documentation, sample preservation techniques, sample shipment methods, sample holding times, and analytical protocols. At any rate, all sampling plans should contain several fundamental elements—particularly as noted in Box 6.4. A detailed discussion of pertinent sampling considerations and strategies for various environmental matrices can be found elsewhere in the literature (e.g., CCME 1993; CDHS 1990; Holmes et al. 1993; Keith 1988, 1991; Lave and Upton 1987; USEPA 1988b, 1989b).

Box 6.4 Elements of a sampling plan

- Background information about impacted region or locale (that includes a description of the problem location and surrounding areas, and a discussion of known and suspected chemical release or contamination sources, probable migration pathways, and other general information about the physical and environmental setting)
- Sampling objectives (describing the intended uses of the data)
- Sampling location and frequency (that also identifies each sample matrix to be collected and the constituents to be analyzed)
- Sample designation (that establishes a sample numbering system for the specific project, and should include the sample number, the sampling round, the sample matrix, and the name of the site or case property)
- Sampling equipment and procedures (including equipment to be used and material composition of equipment, along with decontamination procedures)
- Sample handling and analysis (including identification of sample preservation methods, types of sampling jars, shipping requirements, and holding times)

Sampling and Analysis Design Considerations: A preliminary identification of the types of contaminants, the chemical release potentials, and also the potential exposure pathways should be made very early in a potential chemical exposure characterization effort; this is because these are crucial to decisions on the number, type, and location of samples to be collected. Indeed, knowledge of the type of contaminants will generally help focus more attention on the specific media most likely to have been impacted, or that remains vulnerable. Anyhow, regardless of the medium sampled, data variability problems may arise from temporal and spatial variations in field data. That is, sample composition may vary depending on the time of the year and weather conditions when the sample is collected. Ideally, samples from various media should be collected in a manner that accounts for temporal factors and weather conditions. If seasonal/temporal fluctuations cannot be characterized in the investigation, details of meteorological, seasonal, and climatic conditions during the sampling events must be well documented. For the most part, choosing an appropriate sampling interval that spans a sufficient length of time to allow one to obtain, for example, an independent groundwater sample will generally help reduce the effects of autocorrelation. Also, as appropriate, sampling both 'background' and 'compliance' locations at the same point-in-time should reduce temporal effects. Consequently, the ideal sampling scheme will typically incorporate a full annual sampling cycle. If this strategy cannot be accommodated in an investigation, then at least two sampling events should be considered—and these should probably take place during opposite seasonal extremes.

Similar decisions as above will typically have to be made regarding analytical protocols as well. For instance, due to the differences in the relative toxicity of the different species of some chemicals (as, e.g., chromium may exist as trivalent chromium [Cr+3], or as the more toxic hexavalent chromium [Cr+6]), chemical speciation to differentiate between the various forms of the chemicals of potential concern in relation to a chemical release and potential exposure situation may sometimes be required in the design of analytical protocols.

6.3.1.3 Sampling Protocols

Sampling protocols are written descriptions of the detailed procedures to be followed in collecting, packaging, labeling, preserving, transporting, storing, and documenting samples. In general, every sampling protocol must identify sampling locations—and this should include all of the equipment and information needed for sampling. Box 6.5 lists what might be considered the minimum documentation needed for most environmental sampling activities (CCME 1993; Keith 1988, 1991). In fact, the overall sampling protocol must identify sampling locations, as well as include all of the equipment and information needed for sampling, such as: the types, number, and sizes of containers; labels; field logs; types of sampling devices; numbers and types of blanks, sample splits, and spikes; the sample volume; any composite samples; specific preservation instructions for each sample type; chain of custody procedures; transportation plans; field preparations (such as filter or pH adjustments); field measurements (such as pH, dissolved oxygen, etc.); and the reporting requirements. The sampling protocol should also identify those physical, meteorological, and related variables to be recorded or measured at the time of sampling. In addition, information concerning the analytical methods to be used, minimum sample volumes, desired minimum levels of quantitation, and analytical bias and precision limits may help sampling personnel make better decisions when unforeseen circumstances require changes to the sampling protocol.

At the end of the day, the devices used to collect, store, preserve, and transport samples must *not* alter the sample in any manner. In this regard, it is noteworthy that special procedures may be needed to preserve samples during the period between collection and analysis. In any case, the more specific a sampling protocol is, the less chance there will be for errors or erroneous assumptions.

Box 6.5 Minimum requirements for documenting environmental sampling

- Sampling date
- Sampling time
- Sample identification number
- Sampler's name

(continued)

Box 6.5 (continued)

- Sampling location
- Sampling conditions or sample type
- Sampling equipment
- Preservation used
- Time of preservation
- Auxiliary data (i.e., relevant observations at sample location)

Sampling Strategies and Sample Handling Procedures: Broadly speaking, there are three basic sampling approaches—namely: random, systematic, and judgmental. There are also three primary combinations of each of these—i.e., stratified-(judgmental)-random, systematic-random, and systematic-judgmental (CCME 1993; Keith 1991). Additionally, there are further variations that can be found among the three primary approaches and the three combinations thereof. For example, the systematic grid may be square or triangular; samples may be taken at the nodes of the grid, at the center of the spaces defined by a grid, or randomly within the spaces defined by a grid. A combination of judgmental, systematic, or random sampling is often the most feasible approach to employ in the investigation of potential environmental contamination and chemical release problems. However, the sampling scheme should be flexible enough to allow relevant adjustments/modifications during field activities.

In general, several different methods are available for acquiring data to support chemical exposure characterization programs. The methodology used for sampling can indeed affect the accuracy of subsequent evaluations. It is therefore imperative to select the most appropriate methodology possible, in order to obtain the most reliable results attainable; Holmes et al. (1993), among others, enumerate several factors that should be considered when selecting a sampling method.

6.3.1.4 Laboratory Analytical Protocols

The selection of analytical methods is a key integral part of the processes involved in the development of sampling plans, since this can strongly affect the acceptability of a sampling protocol. For example, the sensitivity of an analytical method could directly influence the amount of a sample needed in order to be able to measure analytes at pre-specified minimum detection (or quantitation) limits. The analytical method may also affect the selection of storage containers and preservation techniques (Keith 1988; Holmes et al. 1993). Thus, the applicable analytical procedures, the details of which are outside the scope of this book, should be strictly adhered to.

Box 6.6 lists the minimum requirements for documenting laboratory work that may be performed to support chemical exposure characterization activities (CCME

1993; USEPA 1989a, b, c, d, e, f). In general, effective analytical programs and laboratory procedures are necessary to help minimize uncertainties in the investigation activities that are required to support potential chemical exposure characterization programs as well as possible remedy decisions. Guidelines for the selection of appropriate analytical methods are offered elsewhere in the literature (e.g., CCME 1993; Keith 1991; USEPA 1989a, b, c, d, e, f). Invariably, analytical protocol and constituent parameter selection are usually carried out in a way that balances costs of analysis with adequacy of coverage.

Box 6.6 Minimum requirements for documenting laboratory work

- Method of analysis
- Date of analysis
- Laboratory and/or facility carrying out analysis
- Analyst's name
- Calibration charts and other measurement charts (e.g., spectral)
- Method detection limits
- Confidence limits
- Records of calculations
- Actual analytical results

Selecting Laboratory Analysis Methods and Analytical Protocols—Laboratory and Analytical Program Requirements: The task of determining the essential analytical requirements involves specifying the most cost-effective analytical method that, together with the sampling methods, will meet the overall data quantity and quality objectives of an investigation activity. Oftentimes, the initial analyses of environmental samples may be performed with a variety of field methods used for screening purposes. The rationale for using initial field screening methods is to help decide if the level of pollution associated with a chemical release and potential chemical exposure situation is high enough to warrant more expensive (and more specific and accurate) laboratory analyses. Indeed, methods that screen for a wide range of compounds, even if determined as groups or homologues, are useful because they allow more samples to be measured faster and far less expensively than with conventional laboratory analyses. In the more detailed phase of the assessment, the sampling analysis is generally performed by laboratory programs that comprise routine and non-routine standardized analytical procedures and associated quality control requirements managed under a broad quality assurance program; these services are provided through routine analytical services and special analytical services.

In general, effective analytical programs and laboratory procedures are necessary to help minimize uncertainties in the investigation activities involving chemical release and potential chemical exposure situations. General guidelines for the selection of analytical methods and strategies are offered elsewhere in the literature (e.g., CCME 1993). Usually there are several methods available for most

environmental analytes of interest. Some analytes may have up to a dozen methods to select from; on the other hand, some analytes may have no proven methods available per se. In the latter case, it usually means that some of the specific isomers that were selected as representative compounds for environmental pollution have not been verified to perform acceptably with any of the commonly used methods.

6.3.2 The Health and Safety Plan

To minimize risks to chemical release investigation personnel (and possible nearby populations) as a result of potential exposure to environmental chemicals, health and safety issues must always be addressed as part of any field investigation activity plan. Proper planning and execution of safety protocols will help protect the chemical release investigation team from accidents and needless exposure to hazardous or potentially hazardous chemicals. In the processes involved, health and safety data are generally required to help establish the level of protection needed for a project investigation crew. Such data are also used to determine if there should be immediate concern for any population living in proximity of the problem location. Details of specific items of required health and safety issues and equipment are discussed elsewhere in the literature (e.g., Cheremisinoff and Graffia 1995; Martin et al. 1992; OBG 1988).

6.3.2.1 Purpose and Scope of a Health and Safety Plan

The purpose of a health and safety plan (HSP) is to identify, evaluate, and control health and safety hazards, and to provide for emergency response during environmental characterization and related fieldwork activities associated with a chemical release and/or exposure situation. The HSP specifies safety precautions needed to protect the populations potentially at risk during chemical release and potential chemical exposure characterization activities. Consequently, a project-specific HSP should be prepared and implemented prior to the commencement of any chemical release characterization or fieldwork activity associated with potential chemical exposure situations. All personnel associated with the project will generally have to comply with the applicable HSP. Also, the scope and coverage of the HSP may be modified or revised to incorporate any changes that may occur in the course of the investigation, or in the working conditions, following the development of the initial HSP.

Overall, the HSP should be developed to be in conformance with all the requirements for occupational safety and health, as well as applicable national, state/provincial/regional and local laws, rules, regulations, statutes, and orders, as necessary to protect all populations potentially at risk. Furthermore, all personnel involved with the environmental and/or chemical release characterization activities would have received adequate training, and there should be a contingency plan in

place that meets all safety requirements. For instance, in the United States, the HSP developed and implemented in the investigation of a potentially contaminated site should be in full compliance with all the requirements of the US Occupational Safety and Health Administration (OSHA) (i.e., OSHA: 29 CFR 1910.120); the requirements of US EPA (i.e., EPA: Orders 1420.2 and 1440.3); and indeed any other relevant state or local laws, rules, regulations, statutes, and orders necessary to protect the populations potentially at risk. Also, all personnel involved with on-site activities would have received a 40-hour OSHA Hazardous Waste Operations and Emergency Response Activities (HAZWOPER) training, including a commonly mandated 8-hour refresher course, where necessary.

As a final note, emergency phone numbers should be compiled and included in the HSP. Also, the directions to the nearest hospital or medical facility, including a map clearly showing the shortest route from the site to the hospital or medical facility should be kept with the HSP at the project location.

6.3.3 The Investigation-Generated/Derived Waste Management Plan

Investigation-derived wastes (IDWs) [also, Investigation-generated wastes (IGWs)] are those wastes generated during environmental and/or chemical release project characterization activities—particularly important in environmental contamination studies. Indeed, there are several ways by which IDWs may be produced.

The overarching objective of an IDW management plan is to specify procedures needed to address the handling of both hazardous and non-hazardous IDWs. The project-specific procedures should prevent contamination of clean areas, and should comply with existing regional and/or local regulations. Specifically, the IDW management plan should include the characterization of IDW; delineation of any areas of contamination; and the identification of waste disposal methods.

In general, the project manager should select investigation methods that minimize the generation of IDWs. After all, minimizing the amount of wastes generated during a chemical release characterization activity generally reduces the number of IDW/IGW handling problems and costs for disposal. Anyhow, insofar as possible, provisions should be made for the proper handling and disposal of IDWs/IGWs locally. In fact, most regulatory agencies do not recommend removal of IDWs from the place or region of origination, especially in situations where the wastes do not pose any immediate threat to human health or the environment; this is because removing wastes from such areas usually would not benefit human health and the environment, and could result in an inefficient spending of a significant portion of the total funds available for the case characterization and corrective action programs.

6.3.4 The Quality Assurance and Quality Control Plan

Quality assurance (QA) refers to a system for ensuring that all information, data, and resulting decisions compiled from an investigation (e.g., monitoring and sampling tasks) are technically sound, statistically valid, and properly documented. The QA program consists of a system of documented checks used to validate the reliability of a data set.

Quality control (QC) is the mechanism through which quality assurance achieves its goals. Quality-control programs define the frequency and methods of checks, audits, and reviews necessary to identify problems and corrective actions, thus verifying product quality. All QC measures should be performed for at least the most sensitive chemical constituents from each sampling event/date.

A detailed quality assurance/quality control (QA/QC) plan, describing specific requirements for QA and QC of both laboratory analysis and field sampling/analysis, should be part of the chemical release assessment and potential exposure characterization project work-plan. The plan requirements will typically relate to, but not limited to the following: the use of blanks, spikes, and duplicates; sample scheduling and sampling procedures; cleaning of sampling equipment; storage; transportation; data quality objectives (DQOs); chain-of-custody; reporting and documentation; audits; and methods of analysis. The practices to be followed by the project team and the oversight review—which will ensure that DQOs are met—must be clearly described in the QA/QC plan.

Several aspects of the chemical release assessment and potential exposure characterization program can, and should indeed be subjected to a quality assessment survey. In part, this is accomplished by submitting sample blanks (alongside the environmental samples) for analysis on a regular basis. The various blanks and checks that are recommended as part of the quality assurance plan include the following particularly important ones:

- *Trip Blank*—required to identify potential contamination of bottles and samples during travel and storage. To prepare the trip blank, the laboratory fills containers with contaminant-free water, and then delivers to the sampling crew; the field sampling crew subsequently ship and store these containers with the actual samples obtained from the project investigation activities. It is recommended to include one trip blank per shipment, especially where volatile chemicals are involved.
- *Field Blank*—required to identify potential contamination of samples during a sample collection activity. This is prepared in the same manner as the trip blank (i.e., the laboratory fills containers with contaminant-free water and deliver to the sampling crew); subsequently, however, the field sampling crew expose this water to air in the locale (just like the actual samples obtained from the project investigation activities). It is recommended to include one field blank per locale or sampling event/day.

- *Equipment Blank*—required in identifying possible contamination from sampling equipment. To obtain an equipment blank, sampling devices are flushed with contaminant-free water, which is then analyzed. Typically, equipment blanks become important only if a problem is suspected (such as using a bailer to sample from multiple groundwater wells).
- *Blind Replicates*—required to identify laboratory variability. To prepare the blind replicate, a field sample is typically split into three containers and labeled as different samples before shipment to the laboratory for analyses. It is recommended to include one blind replicate in each day's activities—or an average of one per 10 to 25 samples, where large numbers of samples are involved.
- *Spiked Samples*—required to help identify likely errors arising from sample storage and analysis activities. To obtain the spiked sample, known concentration(s) are added to the sample bottle and then analyzed. It is recommended to include one spiked sample per locale—or an average of one per 25 samples, where a large number of samples are involved.

Since data generated during a chemical release assessment and potential exposure characterization will provide a basis for risk management and possible remedial decisions, such data should give a valid representation of the true case-specific conditions. The development and implementation of a good QA/QC program during a sampling and analysis activity is indeed critical to obtaining reliable analytical results for the overall characterization program. The soundness of the QA/QC program has a particularly direct bearing on the integrity of the environmental sampling, and also the laboratory work. Thus, the general design process for an adequate QA/QC program, as discussed elsewhere in the literature (e.g., CCME 1994; USEPA 1987, 1988a, b), should be adhered to in the strictest manner practicable.

6.4 General Basic Requirements for Assessing Public Health Risks Arising from Exposure to Chemicals in the Human Environment

Chemical exposure characterizations typically will consist of the planned and managed sequence of activities carried out to determine the nature and distribution of hazards associated with the specific chemical exposure problem. The activities involved usually are comprised of several specific tasks—broadly listed to include the following:

- Problem definition/formulation (including identifying study objectives and data needs).
- Identification of the principal hazards.
- Design of sampling and analysis programs.

- Collection and analysis of appropriate samples.
- Recording or reporting of laboratory results for further evaluation.
- Logical analysis of sampling data and laboratory analytical results.
- Interpretation of study results (consisting of enumeration of the implications of, and decisions on corrective action or remedy).

In any event, to arrive at cost-effective public health risk management decisions, answers will typically have to be generated for several pertinent questions when one is confronted with a potential environmental contamination and/or chemical exposure problem (Box 6.7). In general, when it is suspected that a potential hazard exists at a particular locale, then it becomes necessary to further investigate the situation—and to fully characterize the prevailing or anticipated hazards. This activity may be accomplished by the use of a well-designed data collection in a chemical exposure or environmental investigation program. Ultimately, a thorough investigation—culminating in a risk assessment—that establishes the nature and extent of receptor exposures may become necessary, in order to arrive at appropriate and realistic corrective action and/or risk management decisions.

Box 6.7 Major issues important to making cost-effective public health risk management decisions for chemical exposure problems

- What is the nature of the chemical exposure(s)?
- What are the sources of, and the 'sinks' or receptors for, the chemicals of potential concern?
- What population groups are potentially at risk?
- What are the likely and significant exposure pathways and scenarios that connect chemical source(s) to potential receptors?
- What is the current extent of receptor exposures?
- What is the likelihood of health and environmental effects resulting from the chemical exposure?
- What interim measures, if any, are required as part of a risk management and/or risk prevention program?
- What corrective action(s) may be appropriate to remedy the prevailing situation?
- What level of residual chemical exposures will be tolerable or acceptable for the target receptors?

Finally, it is worth the mention here that, in order to get the most out of the environmental contamination and/or chemical exposure characterization, this activity must be conducted in a systematic manner. Indeed, systematic methods help focus the purpose, the required level of detail, and the several topics of interest—such as physical characteristics of the potential receptors; contacted chemicals; extent and severity of possible exposures; effects of chemicals on populations potentially at risk; probability of harm to human health; and possible residual

hazards following implementation of risk management and corrective action plans. Subsequently, the data derived from the environmental contamination and/or exposure investigation may be used to perform a risk assessment—which then becomes a key element in the public health risk management decision process.