Chapter 2
The Risk Assessment Process

This chapter is an overview of the data collection and evaluation issues that affect the quality and useability of baseline human health risk assessments. Ecological risk assessment is not discussed in this guidance. The discussion focuses on how the quality of environmental analytical data influences the level of certainty of the risk assessment and stresses the importance of understanding data limitations in characterizing risks to human health.

The chapter has two sections. Section 2.1 is an overview of baseline human health risk assessment and the significance of uncertainty in each stage of the risk assessment process. Section 2.2 summarizes the roles and responsibilities of key participants in the risk assessment process.

2.1 OVERVIEW OF BASELINE HUMAN HEALTH RISK ASSESSMENT AND THE EVALUATION OF UNCERTAINTY

The approach to the baseline human health risk assessment process used for exposure to chemicals of potential concern is well established. The National Research Council (NRC) prepared a comprehensive overview of this process (NRC 1983), which has become the foundation for subsequent EPA guidance (EPA 1986a, EPA 1989a, EPA 1989b). RAGS, Part A (EPA 1989a), discusses in detail the human health baseline risk assessment process which is used in the Superfund program.

The risk assessment process has four components:

- Data collection and evaluation,
- Exposure assessment,
- Toxicity assessment, and
- Risk characterization.

Exhibit 3 lists information sought in each component of the baseline risk assessment.

Uncertainty analysis is often viewed as the last step in the risk characterization process. However, as discussed in detail in RAGS, Part A, uncertainty analysis is a fundamental element of each component of risk assessment, and the results for each component require an explicit statement of the degree of uncertainty. These results are the bases for estimating the degree of uncertainty in the risk assessment as a whole. This chapter reviews the issues that determine the level of uncertainty in each component of risk assessment.

> ☛ *To maximize data useability for the risk assessment, the risk assessor must be involved from the start of the RI.*

The importance of obtaining analytical data that fulfill the needs of risk assessment cannot be overstated. The risk assessor must be involved from the start of the risk assessment process to help establish the scope of the investigation and the design of the sampling and analysis program.

All analytical data collected for baseline risk assessment must be evaluated for their useability. The procedures for evaluating the adequacy of the data are documented, along with the resulting estimates of the levels of certainty. Limitations in the analytical data are not the only source of uncertainty in risk assessment. Exhibit 4 identifies some typical sources of uncertainty, inherent in each component of the risk assessment, which restrict the depth and breadth of the evaluation. This guidance deals only with the uncertainty inherent in data collection and evaluation. Consult RAGS, Part A, for a more complete discussion of these and other uncertainties.

Acronyms

ATSDR	Agency for Toxic Substances and Disease Registry
DQO	data quality objective
EPA	U.S. Environmental Protection Agency
GIS	Geographical Information System
HEAST	Health Effects Assessment Summary Tables
IRIS	Integrated Risk Information System
LOAEL	lowest-observable-adverse-effect level
NOAEL	no-observable-adverse-effect level
NRC	National Research Council
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
QA	quality assurance
QAPjP	quality assurance project plan
QC	quality control
RAGS	Risk Assessment Guidance for Superfund
RfC	reference concentration
RfD	reference dose
RI	remedial investigation
RME	reasonable maximum exposure
RPM	remedial project manager
SAP	sampling and analysis plan
SOP	standard operating procedure
UCL	upper confidence limit

EXHIBIT 3. DATA RELEVANT TO COMPONENTS OF THE RISK ASSESSMENT PROCESS

Risk Assessment Component	Data
Data Collection and Evaluation	• Background monitoring data for all affected media. • Environmental data for all relevant media. • List of chemicals of potential concern. • Distribution of sampling data. • Confidence limits surrounding estimates of representative values.
Exposure Assessment	• Release rates. • Physical, chemical and biological parameters, for evaluating transport and transformation of site-related chemicals. • Parameters to characterize receptors according to their activity, behavior and sensitivity. • Estimates of exposure concentrations for all chemicals, environmental media and receptors at risk. • Estimates of chemical intake or dose for all exposure pathways and exposure areas.
Toxicity Assessment	• Toxicity values for all chemicals, exposure pathways, and exposure areas of concern. • Uncertainty factors and confidence measures for RfDs; weight-of-evidence classifications for cancer slope factors.
Risk Characterization	• Hazard quotients and indices. • Estimates of excess lifetime cancer risk. • Uncertainty analysis.

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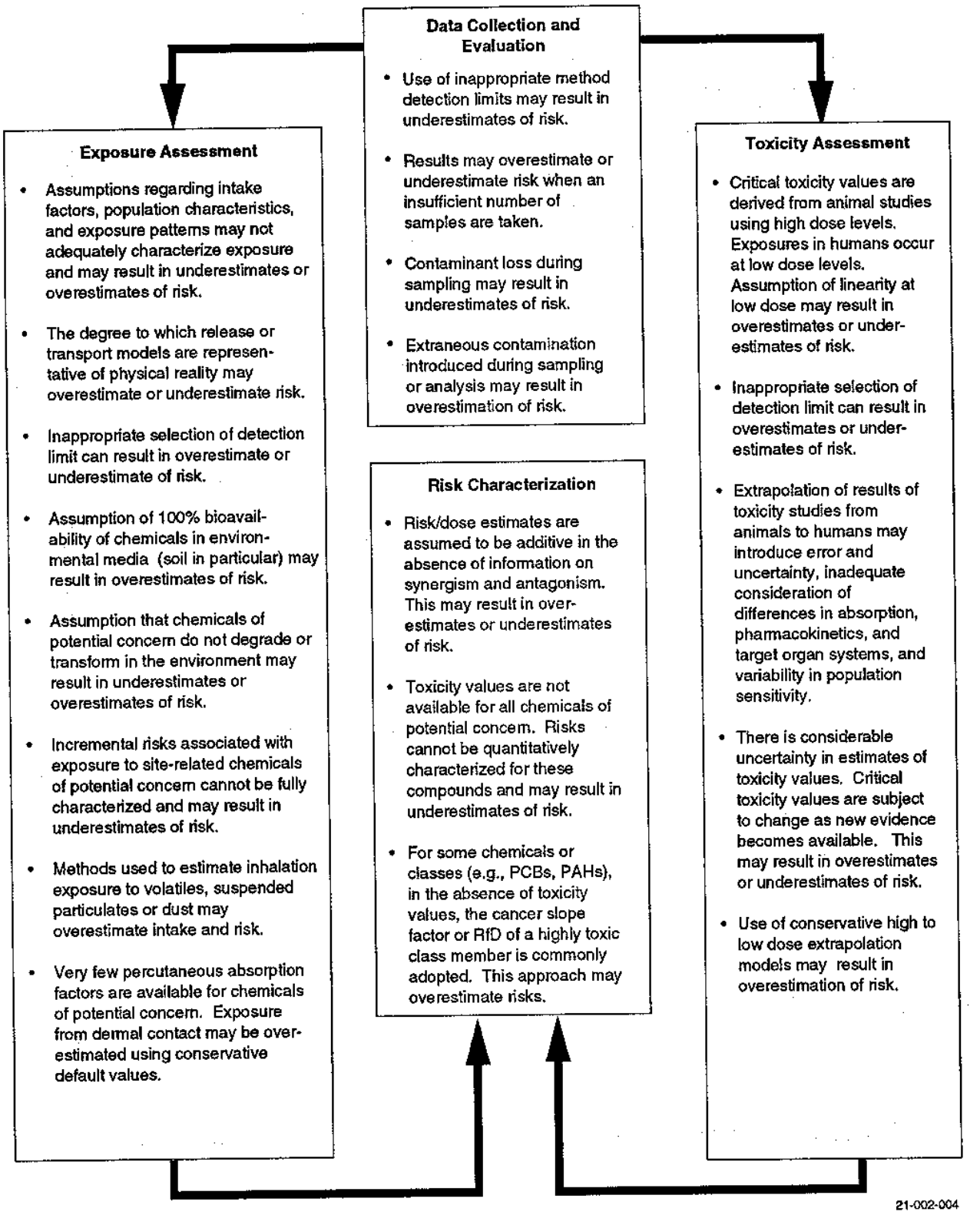
EXHIBIT 4. BASELINE RISK ASSESSMENT PROCESS AND TYPICAL SOURCES OF UNCERTAINTY



Source: Adapted from EPA 1989a.

Risk assessment can be a simple operation, using only screening-level data, or can be comprehensive, requiring a robust data set designed to support statistical analyses. Exhibit 5 discusses the range of uncertainty of baseline risk assessment. The first column in Exhibit 5 defines the range of the analysis from a low to a high degree of uncertainty. The second column describes the associated data useability and limitations in the risk analysis.

- The first level of analysis in Exhibit 5 is a quantitative risk assessment based on a sampling program that can be statistically analyzed. The assessment explicitly bounds and quantitates the uncertainty in all estimates. This analysis may strive to attain an ideal based upon the complexity of the site. The assessment is "quantitative" in that numeric estimates are derived for potentially adverse non-carcinogenic and carcinogenic effects, and in that the level of certainty is quantitated.
- The second level of analysis in Exhibit 5 is a quantitative assessment based on a limited number of samples or on data that cannot be fully quantitated. The risk characterization may include numeric estimates of excess lifetime cancer risks and the calculation of hazard indices. However, the level of analytical uncertainty for these measures may be significant but is either not quantitated or is estimated. Given the limitations of the analytical data, only a qualitative evaluation of the analytical uncertainty is feasible. Most baseline risk assessments fall within this category. Bias may need to be determined for its effect on predicted exposures and consequent risk.
- The third level of the continuum is a qualitative assessment of risk. The assessment is qualitative because no numeric measures can be derived to indicate the potential for adverse effects, and the level of certainty cannot be assessed. The risk to human health is considered only in general terms. Qualitative assessments are based upon limited sources of historical information, such as disposal records, circumstantial evidence of contamination, or preliminary site assessment data.

EXHIBIT 5. RANGE OF UNCERTAINTY OF RISK ASSESSMENT

Range of Analyses	Description/Limitations
Quantitative Assessment of Risk: Uncertainty minimized, quantified, and explicitly stated. Resulting or final uncertainty may be highly variable (either high or low).	Risk assessment conducted using well-designed, robust data sets and models directly applicable to site conditions. Sampling program, based on geostatistical or random design, will support statistical analysis of results. Statistical analysis used to characterize monitoring data. Confidence limits or probability distributions may be developed for all key input variables.
Quantitative Assessment of Risk: Magnitude of uncertainty unknown. No explicit quantitative estimates provided. Qualitative, tabular summary of factors influencing risk estimates may be provided for determination of possible bias in error.	Risk assessment conducted using data set of limited quality and size. No meaningful statistical analysis can be conducted. Results of risk assessment may be quantified but uncertainty surrounding these measures cannot be quantified. Only a qualitative statement is possible. The majority of baseline risk assessments typically fall within this category.
Qualitative Assessment of Risk: Only qualitative statement of uncertainty is possible. Uncertainty is high.	Risks cannot be quantified due to insufficient monitoring or modeling data. Qualitative statement of risks based on historical information or circumstantial evidence of contaminantion is provided. This evaluation must be considered a preliminary, screening level assessment.

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☛ *All data can be used in the baseline risk assessment as long as their uncertainties are clearly described.*

Risk assessments must sometimes be conducted using data of limited quantity and of differing quality. When RPMs and other technical experts involved in the RI understand the quantity and quality of data required in risk assessments, they are better able to design data collection programs to meet these requirements.

2.1.1 Data Collection and Evaluation

Overview of methods for data collection and evaluation. Data collection begins with a statement of the risk assessment purpose and a conceptual model of the current understanding of the problems to be addressed for the site under investigation. The model draws from all available historical data (EPA 1989a). It is first created with a best estimate of the types and concentrations of chemicals, or of key chemicals that are likely to be present, given the history of the site. Site records, site maps, the layout of existing structures, topography, and readily observable soil, water and air characteristics on and off the site help to estimate chemicals of potential concern, likely important exposure pathways, potentially exposed populations, and likely temporal and spatial variation. All of these elements comprise the conceptual model (Exhibit 6 and Appendix IX). Once the conceptual model has been developed and information has been disseminated to project staff, the site is scoped to identify data gaps and requirements for the baseline risk assessment.

Several key issues that are part of the development of data quality objectives (DQOs) should be addressed at scoping (Neptune, *et. al.* 1990):

- The types of data needed (e.g., environmental, toxicological),
- How the data will be used (e.g., site characterization, extent of plume, etc., what chemicals of concern will drive the risk-based decision), and
- The desired level of certainty for the conclusions derived from the analytical data (e.g., what are the probabilities of false positive and false negative results as a function of risk and concentration).

Carefully designed sampling and analysis programs minimize the subsequent need to qualify the environmental data during the data assessment phase. The objective of the data collection effort is to produce data that can be used to assess risks to human health with a known degree of certainty.

A complete list of chemicals of potential concern is produced when the analytical data have been collected and evaluated. This list of analytes is the focus of the risk assessment. EPA no longer advocates the selection of "indicator compounds," because this practice may not accurately reflect the total risk from exposure to multiple site chemicals of potential concern, nor does it improve the quality or accuracy of the risk assessment (EPA 1989a).

Uncertainty in data collection and evaluation. Four principal decisions must be made during data collection and evaluation in the risk assessment:

- The presence and levels of contaminants at the site at a predefined level of detail,
- If the levels of site-related chemicals differ significantly from their background levels,
- Whether the analytical data are adequate to identify and examine exposure pathways and exposure areas, and
- Whether the analytical data are adequate to fully characterize exposure areas.

These decisions are examined in detail in subsequent chapters. The discussion in this section introduces basic concepts.

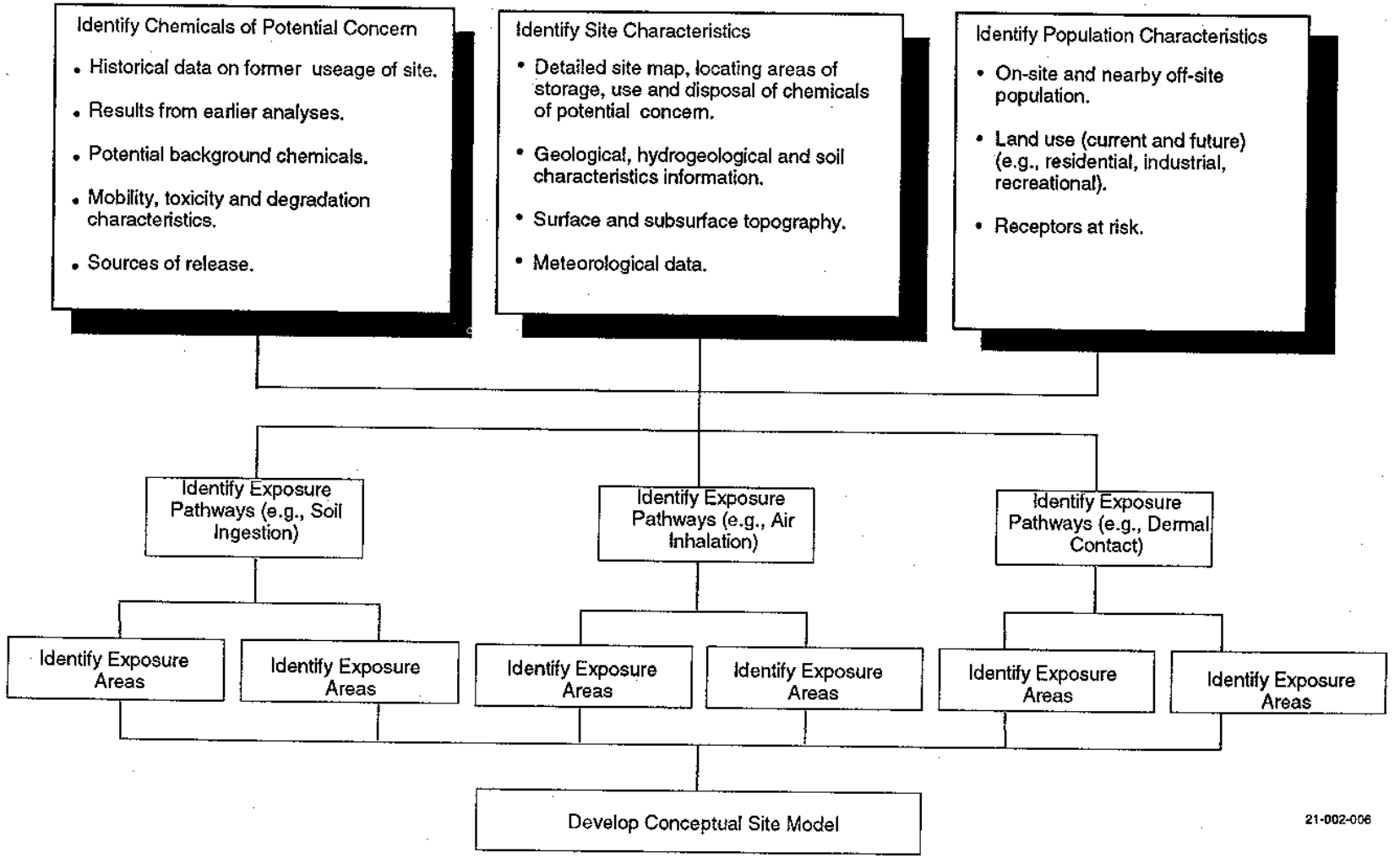
Determining what contamination is present and at what level. Once a site is suspected to be contaminated and chemicals of potential concern have been identified, the levels of chemical contamination in the affected environmental media must be quantitated to derive exposure and intake estimates. Estimates of the site contamination must be produced, with explicit descriptions of the degree of certainty associated with the concentration values.

Variability in observed concentration levels arises from a combination of variance in sampling characteristics of the site, in sampling techniques, and in laboratory analysis. The key issue in optimizing the useability of data for risk assessment is to understand, quantify, and minimize these variabilities.

EPA's objective is to protect human health and the environment. Therefore, the design of RI programs is intended to minimize two potential errors:

- Not detecting site contamination that is actually present (i.e., false negative values), and
- Deriving site concentrations that do not accurately characterize the magnitude of contamination.

EXHIBIT 6. DEVELOPMENT OF CONCEPTUAL SITE MODEL



Determining if site concentrations differ significantly from background concentrations. A fundamental decision in baseline risk assessments is whether the site poses an increased risk to human health and the environment. The decision depends on the degree of certainty that the background concentrations are significantly different from the concentrations of the chemicals of potential concern at the site. Generally, this question can be confidently answered only if the design of the sampling program accommodates the collection of both site and background samples and if the selection of analytical methods is appropriate.

The differences between site and background concentrations is evaluated by comparing observed levels of chemicals of potential concern at the site with measured background concentrations of the same chemicals in the same environmental media. Statistically, this is a test of the null hypothesis, that the mean concentration of a chemical at the study area is not significantly different from the mean concentration of the chemical at the background location. (Historical on-site levels or nearby off-site levels may be used to supplement background data. An example of an off-site area is the 4-mile radius used for the air exposure pathway in the Hazard Ranking System.) If data from background samples are clearly different from the results of site monitoring (e.g., mean chemical concentrations differ consistently by two orders of magnitude), statistical analysis of the data may not be necessary. Under such circumstances, RAGS indicates that the primary issue is establishing a reliable representation of the extent of the contaminated area. Determining extent of contamination is not discussed in this guidance and involves different decisions, DQOs, and sampling designs. If the results of site monitoring are less than two orders of magnitude above background, the procedures used for sampling and analysis for risk assessment should follow the recommendations of Chapter 4.

The null hypothesis is always evaluated and accepted or rejected with a specified level of certainty. This level of certainty is defined by the significance, or confidence, level. A type I error is the probability that the null hypothesis is rejected when in fact it is true (which contributes to false positive conclusions). A type II error is the probability that the null hypothesis is accepted when it is false (a false negative conclusion). How sampling and analysis design affects the likelihood of these two types of errors is described in Chapter 4.

Evaluating whether analytical data are adequate to identify and examine exposure pathways and their exposure areas. Identifying and delineating exposure pathways and their exposure areas are important in identifying potentially exposed populations and for developing intake estimates. In the baseline risk assessment, the risk assessor combines data on contamination with information on human activity patterns to identify exposure pathways and to determine the exposure area. The ability to accomplish this depends on the adequacy of analytical data.

Sampling should be designed to provide representative data for exposure areas at a site, to address hot spots, to evaluate the transport of site-related chemicals of potential concern, and to facilitate the identification of all exposure pathways. A well-designed sampling and analysis program results in data of known quality and quantification of spatial and temporal variability; it specifies how to interpret the magnitude of observed values (such as by comparison with background levels or some other benchmark). Analytical data should characterize the extent of contamination at the site in three dimensions.

Evaluating whether analytical data are adequate to fully characterize exposure areas. Heterogeneity should be considered in the environmental medium under evaluation. Hot spots need to be identified and characterized. Neptune, *et. al.* 1990, have proposed the concept of an "exposure unit" as the area over which receptors integrate exposure. This concept establishes a basis for summarizing the results of monitoring and transport modeling. The sampling and analysis program must be designed to enable the risk assessor to refine the initial characterization of exposure pathways and to spatially and temporally identify the critical areas of exposure.

2.1.2 Exposure Assessment

Overview of methods for exposure assessment. The objectives of the exposure assessment are:

- To identify or define the source of exposure,
- To define exposure pathways along with each of their components (e.g., source, mechanism of release, mechanism of transport, medium of transport, etc.),
- To identify potentially exposed populations (receptors), and
- To measure or estimate the magnitude, duration, and frequency of exposure to site contaminants for each receptor (or receptor group).

Actions at hazardous waste sites are based on an estimate of the reasonable maximum exposure (RME) expected to occur under both current and future conditions of land use (EPA 1989a). EPA defines the RME as the highest exposure that is reasonably expected to occur at a site

over time. RMEs are estimated for individual pathways and combined across exposure pathways if appropriate. Once potentially exposed populations are identified, environmental concentrations at points of exposure must be determined or projected. Intake estimates (in mg/kg-day) are then developed for each chemical of potential concern using a conservative estimate of the average concentration to which receptors are exposed over the exposure period. (RAGS recommends a 95% upper confidence limit (UCL) on the arithmetic mean.) The concentration estimate is then combined with other exposure parameters (e.g., frequency, duration, and body weight) to calculate intake.

In the risk assessment report, estimates of intake are accompanied by a full description (including sources) of the assumptions made in their development. This information may be used subsequently in sensitivity and uncertainty analyses in the risk characterization.

Uncertainty analysis in exposure assessment. Exposure assessments can introduce a great deal of uncertainty into the baseline risk assessment process. Small measures of uncertainty in each of the input parameters which comprise an exposure scenario may result in substantial uncertainty in the final assessment. The largest measure of uncertainty is associated with characterizing transport and transformation of chemicals in the environment, establishing exposure settings, and deriving estimates of chronic intake. The ultimate effect of uncertainty in the exposure assessment is an uncertain estimate of intake.

The following sections discuss the significance of the uncertainty in the analytical data set on selected aspects of exposure assessment. For a more complete discussion of the exposure assessment process, the reader is referred to RAGS, Part A.

Characterizing environmental fate, identifying exposure pathways, and identifying receptors at risk. An evaluation of the transport and transformation of chemicals in the environment is conducted for several reasons:

- To understand the behavior of site-related chemicals of potential concern,
- To project the ultimate disposition of these chemicals,
- To identify exposure pathways and receptors potentially at risk, and
- To characterize environmental concentrations at the point of exposure.

These evaluations cannot be accomplished with any degree of certainty if the analytical data are inadequate.

Monitoring data are most appropriately used to estimate current or existing exposure when direct contact with contaminated environmental media is the primary concern. Modeling may be required, however, in order to evaluate the potential for future exposure, or exposure at a distance from the source of release, or to predict present concentrations where measurement is too costly. In each case, success in estimating potential exposures depends heavily on the adequacy of the analytical data.

Environmental fate and transport assessment often uses models to estimate concentrations in environmental media at points distant from the source of release. Models, of necessity, are simplifications of a real, physical system. Consequently, it is critical that the limitations of the model (the way that the model differs from reality) be understood and considered when applying the model to a particular site. The degree to which the model differs from reality (in critical areas of the analysis) contributes to the uncertainty of the analysis. Transport models are commonly selected for their utility in describing or interpreting a set of monitoring data. Chemical transport models must be carefully selected for their ability to meaningfully characterize the behavior of chemicals in the environmental medium for the specific site under investigation. Models that are inappropriate for the geophysical conditions at the site will result in errors in the exposure assessment. For example, the model may be designed to predict contaminant movement through sand, while soils at the site are primarily made up of clay. Additionally, if the analytical data set is severely limited in size or does not accurately characterize the nature of contamination at the site, a transport model cannot be properly selected or accurately calibrated. This introduces additional uncertainty.

> ☛ *Uncertainty in the analytical data, compounded by uncertainty caused by the selection of the transport models, can yield results that are meaningless or that cannot be interpreted.*

Estimating chemical intake. Uncertainties in all elements of the exposure assessment come together, and are compounded, in the estimate of intake. It is here that the professional judgment of the risk assessor is particularly important. The risk assessor must examine and interpret a diversity of information:

- The nature, extent and magnitude of contamination,
- Results of environmental transport modeling,
- Identification of exposure pathways and areas,

- Identification of receptor groups currently exposed and potentially exposed in the future, and
- Activity patterns and sensitivities of receptors and receptor groups.

Based on this information, the risk assessor characterizes the exposure setting and quantifies all parameters needed in the equations to estimate intake (EPA 1989a). Chemical intake is a function of the concentration of the chemical at the point of contact, the amount of contaminated medium contacted per unit time or event, the exposure frequency and duration, body weight, the ability of the chemical to penetrate the exchange boundary, and the average time period during which exposure occurs. Exhibit 7 is the generic form of the intake equation used in exposure assessment.

The specific form of the intake equation varies depending upon the exposure pathway under consideration (e.g., ingestion, inhalation, dermal contact) (EPA 1989a). Each of the variables in these equations, including chemical concentration, is commonly characterized as a point estimate. However, each intake variable in the equation has a range of possible values. Site-specific characteristics determine the selection of the most appropriate values. In an effort to increase consistency among Superfund risk assessments, EPA has established standardized exposure parameters to be used when site-specific data are unavailable (EPA 1991b). Note that the combination of all factors selected should result in an estimate of reasonable maximum exposure for each chemical in each pathway (EPA 1989a).

For most risk assessments, it may not be possible, nor necessarily advantageous, to develop a quantitative uncertainty analysis. In these cases, a summary of major assumptions and their anticipated effects on final exposure estimates should be included to provide a qualitative characterization of the level of certainty in the intake estimates.

2.1.3 Toxicity Assessment

Overview of methods for toxicity assessment. The objectives of toxicity assessment are to evaluate the inherent toxicity of the compounds at the site, and to identify and select toxicity values to evaluate the significance of receptor exposure to these compounds. Toxicity assessments rely on scientific data available in the literature on adverse effects on humans and nonhuman species.

Several values of toxicity are important in human health risk assessments. Reference doses (RfDs) and reference concentrations (RfCs) are used for oral and inhalation exposure, respectively, to evaluate non-carcinogenic and developmental effects; cancer slope factors and unit risk estimates are used for the oral and inhalation pathways for carcinogens.

RfDs and RfCs are values developed by EPA to evaluate the potential for non-carcinogenic effects in humans. The RfD is defined as an estimate (with uncertainty spanning an order of magnitude or more) of a daily exposure level for human populations, including sensitive sub-populations, that is likely to be without an appreciable risk of adverse health effects over the period of exposure (EPA 1989a). Subchronic or chronic RfDs may be derived for a chemical for intermediate or long-term exposure scenarios. These values are typically derived from the no-observable-adverse-effect level (NOAEL) or the lowest-observable-adverse-effect level (LOAEL) and the application of uncertainty and modifying factors (EPA 1989a). Uncertainty factors are used to account for the variation in sensitivity of human sub-populations and the uncertainty inherent in extrapolating the results of animal studies to humans. Modifying factors account for additional uncertainties in the studies used to derive the NOAEL or LOAEL.

Cancer slope factors and unit risk values are defined as plausible, upper-bound estimates of the probability of cancer response in an exposed individual, per unit intake over a lifetime exposure period (EPA 1989a). EPA commonly develops slope factors for carcinogens with weight-of-evidence classifications that reflect the likelihood that the toxicant is a human carcinogen (EPA 1989a).

To reduce variability in toxicological values used for risk assessment, a standardized hierarchy of available toxicological data is specified for Superfund. The primary source of information for these data is the Integrated Risk Information System (IRIS) database (EPA 1989d). IRIS consists of verified RfDs, RfCs, cancer slope factors, unit risks, and other health risk and EPA regulatory information. Data in IRIS are regularly reviewed and updated by an EPA workgroup. If toxicity values are not available in IRIS, the EPA *Health Effects Assessment Summary Tables* (HEAST) (EPA 1990a) are used as a secondary current source of information. Additional sources of toxicity information are provided in RAGS.

The toxicity assessment is conducted parallel with the exposure assessment, but may begin as early as the data collection and evaluation phase. As chemicals of potential concern are identified at the site, the toxicologist begins to identify the appropriate toxicity values. A well-designed sampling and analysis program facilitates timely identification of the chemicals that will be the focus of the risk assessment.

EXHIBIT 7. GENERIC EQUATION FOR CALCULATING CHEMICAL INTAKES

$$I = C \times \left(\frac{CR \times EFD}{BW}\right) \times \frac{1}{AT}$$

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 time 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)

Source: RAGS (EPA 1989a).

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Uncertainty analysis and toxicity assessment. The toxicity assessment is another contributor to uncertainty in risk assessment. Limitations in the analytical data from environmental samples affect the results of the toxicity assessment, but not to the extent that they affect other components of the risk assessment process. Data on physical and chemical parameters that may influence bioavailability can influence route-to-route and vehicle-related adjustments to toxicity values. The selection of appropriate toxicity values is influenced by monitoring data from environmental samples to the extent that this information assists in identifying chemicals of potential concern, exposure pathways, and the time periods over which exposure may occur. Based on this information, the toxicologist identifies sub-chronic or chronic RfDs, RfCs, and cancer slope factors for oral, dermal, and inhalation exposure pathways.

A list of toxicity values for risk assessment should include an indication of the degree of certainty associated with these values. Weight-of-evidence classifications provide a qualitative estimate of certainty and should be included in the discussion of cancer slope factors. Uncertainty and modifying factors used in deriving RfDs and RfCs should also be included in the discussion of non-carcinogenic effects.

2.1.4 Risk Characterization

Overview of methods for risk characterization. The last step in the baseline risk assessment is risk characterization. This is the process of integrating the results of the exposure and toxicity assessments, by comparing estimates of intake with appropriate toxicological values to determine the likelihood of adverse effects in potentially exposed populations. Risk characterization is considered separately for carcinogenic and non-carcinogenic effects, because organisms typically respond differently following exposure to carcinogenic and non-carcinogenic agents. For non-carcinogenic effects, toxicologists recognize the existence of a threshold of exposure below which there is likely to be no appreciable risk of adverse health impacts in an exposed individual. It is the current EPA position that exposure to any level of carcinogenic compounds is considered to carry a risk of adverse effect, and that exposure is not characterized by the existence of a threshold.

EPA's procedure for calculating risk from exposure to carcinogenic compounds (EPA 1986a, EPA 1989a, EPA 1989b) uses a non-threshold, dose-response model. The model is used to calculate a cancer slope factor (mathematically, the slope of the dose-response curve) for each chemical. Generally, the cancer slope factor is used in conjunction with the chronic daily intake to derive a probabilistic upperbound estimate of excess lifetime cancer risk to the individual.

The dose-response model most commonly used by EPA in deriving the cancer slope estimates is linearized and multistage. The mathematical relationship of the model assumes that the dose-response relationship is linear in the low-dose portion of the curve (EPA 1989a). Given this assumption, the slope factor is a constant, and risk is directly proportional to intake.

The recommended practice for evaluating the potential for non-carcinogenic effects is to compare the RfD of a given chemical to the estimated intake of the potentially exposed population from a given exposure pathway (EPA 1989a). This ratio (intake/RfD) is termed the "hazard quotient." It is not a probabilistic estimate of risk, but simply a measure of concern, or an indicator of the potential for adverse effects. A more detailed discussion of risk characterization is presented in RAGS. Further discussion of methods for risk characterization, and of specific factors such as metabolic rate factors, gender differences, and variable effects due to multiple chemicals of potential concern, is available from many sources (EPA 1988a, EPA 1989b, EPA 1989c).

Uncertainty analysis in risk characterization. No risk assessment is certain. Risk assessment is a process that provides an estimate of potential (present and future) individual risk, along with the limitations or uncertainties associated with the estimates. The most obvious effect of limitations in the analytical data on risk characterization is the ability to accurately estimate the potential for adverse effects in potentially exposed individuals. Clearly, if the available monitoring data do not facilitate a meaningful determination of RME values, the risk estimates will directly reflect this uncertainty.

> ☛ *Uncertainties in toxicological measures and exposure assessment are often assumed to be greater than uncertainties in environmental analytical data; thus, they are assumed to have a more significant effect on the uncertainty of the risk assessment.*

Resource and time constraints often limit the opportunity to develop a well-designed and comprehensive data set. Risk assessments must be conducted using the available information, even when there is no opportunity to improve the data set. However, the results should be presented with an explicit statement regarding limitations and uncertainty.

If possible, a sensitivity analysis should be conducted to bound the results of risk assessments. A simple approach might consist of establishing the range of potential values (e.g., minimum, most likely, and maximum) for key input variables and discussing the influence on the resulting risk estimates. The key variables can then be ranked with respect to the magnitude of potential effect on the risk estimates. In certain instances, more

quantitative approaches to uncertainty analysis may be useful if they can be supported by the available information. Combining probability distributions using Monte Carlo techniques is one commonly cited example (EPA 1988b, EPA 1989a, Finkel 1990). An overview of recommended methods for assessment of uncertainty in risk characterization is presented in RAGS. Risk*Assistant, a software tool developed for EPA, provides an uncertainty analysis that determines the effect on the final risk estimate of using alternative parameter values, indicates the relative contribution of each pathway to risks from the contaminated media, and (for carcinogenic risks) determines the percentage of total risk from a contaminant in each medium (Thistle Publishing 1991). A more detailed consideration of uncertainty analysis in risk assessment may be found in *Methodology for Characterization of Uncertainty in Exposure Assessment* (EPA 1985) and *Confronting Uncertainty in Risk Management: A Guide for Decision-Makers* (Finkel 1990).

2.2 ROLES AND RESPONSIBILITIES OF KEY RISK ASSESSMENT PERSONNEL

The risk assessor generally enlists the participation of individuals with specific skills and technical expertise. The quality and utility of the baseline risk assessment will ultimately depend on the planning and interaction of these technical professionals. Key participants include the RPM and the risk assessor, who are primarily responsible for ensuring that data collected during the RI are useable for risk assessment activities. Other participants include hydrogeologists, chemists, statisticians, quality assurance staff, and other technical support personnel involved in planning and conducting the RI. Exhibit 8 summarizes the roles and responsibilities of the risk assessment participants.

2.2.1 Project Coordination

All data collection activities that support the risk assessment are coordinated by the RPM. The RPM's responsibilities begin upon site listing and continue through deletion of the site from the National Priorities List. A network of technical experts, including representatives of other agencies involved in human health or environmental/ecological assessments or related issues, is established at the start of the RI. This ensures that the potential for adverse effects to human health and the environment is adequately assessed during the RI. To successfully plan and direct the sampling and analysis effort, the RPM must facilitate interaction among key participants.

2.2.2 Gathering Existing Site Data and Developing the Conceptual Model

The RPM is responsible for gathering and evaluating all historical and existing site data. This is an important element in planning the scope of the risk assessment and data collection, and in determining additional data needs. Sources of information especially pertinent for risk assessment include data from potentially responsible parties, industrial records identifying chemicals used in processes, preliminary natural resource studies, Agency for Toxic Substances and Disease Registry (ATSDR) health studies, environmental impact statements, transport manifests, site records, site inspection documents, and site visits. Aerial photographs and site maps showing past and present locations of structures and transportation corridors should also be collected. The RPM should also consider the application of a computer-based Geographical Information System (GIS) as a major tool.

The RPM should ensure that a broad spectrum analysis was conducted at the site for all media and should review industry-specific records to minimize the potential for false negatives. From the inspection of historical data and broad spectrum analyses, a preliminary list of the chemicals of potential concern is prepared to assist in scoping and in developing the conceptual model of the site. Once all the existing historical site data have been collected, the RPM works with the risk assessor to develop a conceptual model. The conceptual model is a depiction and discussion of the current understanding of the contamination, the sources of release to the environment, transport pathways, exposure pathways, exposure areas and receptors at risk. Preliminary identification of potential exposure pathways at the site under investigation is particularly important for the design of a thorough data collection effort. The conceptual site model should be provided to all key participants in the RI during the project scoping and should be included in the workplan. As work progresses and the site is better characterized, the RPM and the risk assessor should update the conceptual model.

2.2.3 Project Scoping

The adequacy of the sampling and analysis effort determines the quality of the risk assessment. Therefore, it is imperative that the risk assessor be an active member of RI planning and continue to be involved during the entire course of the project.

EXHIBIT 8. ROLES AND RESPONSIBILITIES OF RISK ASSESSMENT TEAM MEMBERS

Remedial project manager

- Directs, coordinates and monitors all activities.
- Establishes network with other data users including federal, state and local agencies.
- Creates conceptual model.
- Gathers existing site data.
- Organizes scoping meetings.
- Controls budget and schedule.
- Guides preparation of QA documents.
- Ensures that the risk assessor receives preliminary analytical data.
- Contributes to data assessment.
- Develops preliminary list of chemicals of potential concern.
- Resolves problems affecting RI objectives, including risk assessment issues (e.g., resampling, reanalysis).

Risk assessor

- Reviews all relevant existing site data.
- Assists the RPM in developing the conceptual model and the preliminary list of chemicals of potential concern.
- Contributes to recommendations on sampling design, analytical requirements, including chemicals of potential concern, detection limits and quality control needs during project scoping.
- Helps to refine the conceptual model.
- Communicates frequently with the RPM, hydrogeologist and chemist to ensure that data collection meets needs.
- Reviews and contributes to SAP and QA documents.
- Assesses preliminary data as soon as available to verify conceptual site model.
- Specifies additional needs.
- Assesses reviewed data for useability in risk assessment.
- Communicates all site activities with specific groups, such as chemists.
- Prepares risk assessment.

Hydrogeologist, chemist and other technical support

- Provides technical input to scoping.
- Prepares/provides input to SAP and QA documents in support of risk assessment data needs.
- Communicates frequently with the RPM and/or risk assessor on status of data collection and issues affecting data.
- Provides preliminary data to the RPM and/or risk assessor for review.
- Supports fate and transport modeling for the exposure assessment.
- Implements corrective actions to improve data useability.

Quality assurance specialist

- Responsible for data quality review and technical assistance in preparing QA documents.
- Provides historical performance QA data or recommendations for appropriate QC.
- Ensures adequate QA procedures are in place, including field and analytical audits.

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☛ *Analytical data collected solely for other purposes may not be of optimal use to the risk assessment.*

Data obtained solely with the aim of characterizing the nature and extent of contamination at a site may not fully support the needs of the risk assessor in quantitating exposure, and therefore the potential for adverse effects in human and nonhuman receptors. Data on the nature and extent of contamination may therefore be rejected by the risk assessor, requiring an additional round of sampling. For example, data identifying the boundaries of the site may not be representative of the level of contamination within an exposure area. Therefore, it is important to maintain the risk assessment data requirements as a high priority throughout remedial investigations.

Sampling and analysis methods discussed during scoping should ultimately be based on site-specific data needs. The RPM, risk assessor, hydrogeologist, statistician, and project chemist must maintain open communication during scoping and throughout the RI to ensure that this occurs. Data review and deliverable requirements should be determined during the scoping meetings so that these specifications can be included in the sampling and analysis plan (SAP) for the RI. The RPM should prepare a checklist of considerations for the scoping meetings and provide it to all individuals involved. Exhibit 9 presents an example checklist of items useful for risk assessment to be considered by the RPM during scoping. Chapters 3 and 4 give specific guidance for planning the data collection efforts to support risk assessments.

2.2.4 Quality Assurance Document Preparation and Review

After scoping, the RPM guides the preparation of the workplan and quality assurance documents. The workplan, the SAP, and the quality assurance project plan (QAPjP) should document the combined decisions of the RPM, risk assessor, and other project staff.

EXHIBIT 9. EXAMPLE RISK ASSESSMENT CHECKLIST FOR USE IN SCOPING

- Has all historical information been gathered and characterized and is it appropriate and available for use?
- What sample matrices should be investigated?
- What analytical methods should be used?
- Are the methods appropriate for risk assessment, given specific contaminants present and their toxicity?
- Will any special quality control requirements be necessary?
- Who will conduct the analysis (e.g., which type of laboratory)?
- What analytical data sources should be used (fixed laboratory and/or field analysis)?
- What sampling designs are appropriate?
- How many samples will be needed?
- How will the data review be accomplished?
- What types of deliverables will be required? Specify the types of deliverables required from both laboratory and data validation.
- What budget or other limitations constrain data collection (e.g., due date, contractor availability)?

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Particular emphasis is placed on establishing confidence limits, acceptable error, and level of quality control (discussed in Chapter 3). This facilitates cost-effective design of the sampling and analytical program and minimizes the collection of data of limited use for risk assessment.

The risk assessor reviews the workplan and SAP to ensure that the relevant data quality issues, sampling design, analytical needs, and data assessment procedures are adequately addressed for risk assessment. Exhibits 10 and 11 provide checklists to aid the review of the workplan and SAP.

2.2.5 Budgeting and Scheduling

As the overall site manager, the RPM must address and balance risk assessment data needs with other data use needs, such as health and safety, treatability studies, transport, and the nature and extent of contamination. The risk assessor is responsible for identifying specific data requirements for risk assessment and communicating these needs to the RPM. The RPM is responsible for developing and implementing the schedule for acquiring the data. Balancing costs and services while adhering to the schedule is a major responsibility of the RPM.

The RPM must coordinate the use of analytical services. Data from different analytical sources provide the flexibility needed to balance cost with sampling needs and time constraints. The advantages and disadvantages of field analyses and fixed laboratory analyses should be considered, as described in Chapters 3 and 4. The risk assessment participants can assist in the development of field sampling plans and the selection of appropriate analytical methods that will provide the risk assessor with a set of useable data, within the budgeting and scheduling constraints of the RPM.

2.2.6 Iterative Communication

Continuing, open, and frequent communication among the participants is critical to the success of the RI and baseline risk assessment. A single meeting or discussion is rarely adequate to ensure that all relevant issues have been addressed. Development of the risk assessment within the RI report is an iterative process of action, feedback, and correction or adjustment.

After review of the workplan, the SAP, and the QAPjP, the RPM monitors the flow of information. The risk assessor assists the RPM to ensure that the data produced are in compliance with the requirements of the workplan and SAP. Key questions they consider once the data become available are:

- Have correct sampling protocols been followed?
- Have all critical samples been collected?

EXHIBIT 10. CHECKLIST FOR REVIEWING THE WORKPLAN

- Does the workplan address the objectives of baseline risk assessment?
- Does the workplan document the current understanding of site history and the physical setting?
- Have historical data been gathered and assessed?
- Has information on probable background concentrations been obtained?
- Does the workplan provide a conceptual site model for the baseline risk assessment, including a summary of the nature and extent of contamination, exposure pathways of potential concern, and a preliminary assessment of potential risks to human health and the environment?
- Does the workplan document the decisions and evaluations made during project scoping, including specific sampling and analysis requirements for risk assessment?
- Does the workplan address all data requirements for the baseline risk assessment and explicitly describe the sampling, analysis and data review tasks?

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EXHIBIT 11. CHECKLIST FOR REVIEWING THE SAMPLING AND ANALYSIS PLAN

- Do the objectives of the QAPjP and the field sampling plan meet risk assessment needs established in the scoping meeting?
- Are QA/QC procedures provided for in the SAP adequate for the purposes of the baseline risk assessment?
- Have the data gaps for risk assessment that were identified in the RI workplan been adequately addressed in the SAP?
- Are there sufficient QC samples to measure the likelihood of false negatives and false positives, and to determine the precision and accuracy of resulting data?
- Have analytical methods been selected that have detection limits adequate to quantitate contaminants at the concentration of concern?
- Have SOPs been prepared for sampling, analysis and data review?
- Will the sampling and analysis program result in the data needed for the baseline risk assessment:
  - -- to address each medium, exposure pathway and chemical of potential concern,
  - -- to evaluate background concentrations,
  - -- to provide detail on sample locations, sampling frequency, statistical design and analysis,
  - -- to evaluate temporal as well as spatial variation, and
  - -- to support evaluation of current as well as future resource uses?

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- Have the samples been analyzed as requested?
- Are data arriving in a timely fashion?
- Have appropriate sample quantitation limits/detection limits been achieved?
- Has quality assurance been addressed as stated in the SAP and QAPjP?
- Have the data been reviewed as stated in the SAP?
- Is the quality of the analytical data acceptable for their intended use?

Based upon these considerations, the RPM, risk assessor and other technical team members must jointly determine if any corrective actions are needed, such as requesting additional sampling, using alternative analytical methods, or reanalyzing samples.

2.2.7 Data Assessment

The RPM and risk assessor work with other participants to identify a list of chemicals of potential concern and decide on data review procedures. This information is developed during project scoping and incorporated into the workplan and SAP. The RPM, risk assessor, and project chemist should agree on the type and level of data review required for both positive and "non-detect" results. Typically, the RPM assesses the overall data reviewed by the chemist, and the risk assessor reviews data relevant to risk assessment, unless other arrangements have been established and explicitly stated in the SAP.

The risk assessor may request preliminary data, or results that have received only a partial review, in order to expedite the risk assessment to save time and resources. Preliminary data can be used to validate the conceptual model or to begin the toxicity assessment. The data may also indicate a need for modifying sampling or analytical procedures. However, preliminary data should **not** be used in calculating risk. Once the full analytical data set is obtained, the RPM and risk assessor should consult with the project chemist and statistician to assess the utility of all available information.

2.2.8 Assessment and Presentation of Environmental Analytical Data

Once environmental data are evaluated in the data review process, the risk assessor develops a final data set for use in the baseline risk assessment. All chemicals of potential concern should now be identified. The risk assessor prepares summary tables containing the following information:

- Site name and sample locations,
- Number of samples per defined, representative area of each medium (e.g., do not count background samples together with other samples),
- Sample-specific results,
- Analyte-specific sample quantitation limits,
- Number of values above the quantitation limit,
- Measures of central tendency (e.g., 95% UCL on the arithmetic mean of the environmental concentration),
- Specifications for the treatment of detection or quantitation limits and treatment of qualified data, and
- Ranges of concentrations.

All assumptions, qualifications, and limitations should be explicitly stated in the tables. The risk assessor provides the final data summary tables to the RPM, project hydrogeologist, project chemist, and other appropriate project staff for review. These are the data that will be used in the baseline risk assessment to determine the potential risk to human health. It is essential, therefore, that this information consists of the best data available and reflects the collective review of the key participants in the risk assessment. An example of such a set of data is given in Appendix I.