United States Environmental Protection Agency

Exposure Assessment (EXA) Course Series

Approaches for Quantifying Exposure

Reading Packet

EXA 402



EPA's Risk Assessment Training and Experience (RATE) Program

EXA 402: Approaches for Quantifying Exposure

READING PACKET

Exposure Assessment (EXA)
Course Series

EPA's Risk Assessment Training and Experience Program

EXA 402: Approaches for Quantifying Exposure

Selecting the approach for quantifying exposure and dose as well as determining the appropriate type and scope of the study are important first steps in planning an exposure assessment. This course is designed to explore the various approaches that may be used to measure or model exposure, including point of contact measurements, scenario evaluation methods, and dose reconstruction approaches. The purpose and utility of these approaches as well as their strengths and weaknesses will be covered. Participants will also be introduced to types of quantitative methods (e.g., deterministic or probabilistic) and variations in scope of assessments (e.g., single or multiple chemicals; national-scale, or specific location or industry). The use of exposure descriptors in the exposure assessment planning process will also be discussed.

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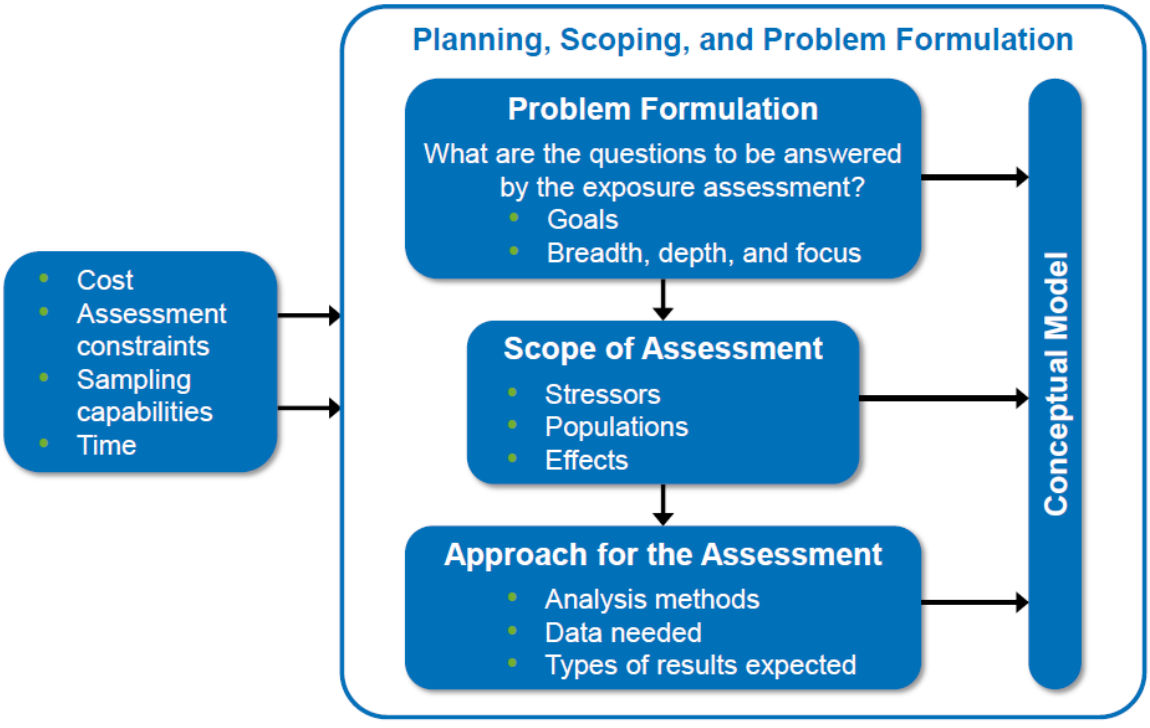
1. INTRODUCTION TO APPROACHES FOR QUANTIFYING EXPOSURE

This course explores the various approaches that can be used to measure or model exposure. The first part of the course discusses each of the types of approaches used in exposure assessment, issues related to defining the scope of the exposure assessment, and some ways to describe different types of exposure and estimates of exposure. The second part of the course focuses on three common exposure quantification approaches: point of contact assessment, scenario evaluation, and reconstruction of dose.

The exposure assessment process begins with problem formulation as shown in Figure 1. The scope and parameters of an exposure assessment are dictated by the questions we want to answer regarding exposure. This makes problem formulation a critical first step in the process. We need to articulate our questions at the outset of an exposure assessment—during the problem formulation stage—because they help structure the design of the analysis and allow risk assessors, risk managers, and stakeholders to make sure they are all on the same page regarding the goals, depth, and focus of the exposure assessment. Articulating the exposure assessment questions helps us to develop a conceptual model for the assessment.

Specifying the scope of the assessment helps us to further refine the conceptual model. After formulating our exposure assessment questions and defining the scope of the assessment, we can decide on our preliminary approach for the assessment. As we go through the problem formulation and planning and scoping phase of our assessment, it is also important to consider cost, assessment constraints, sampling capabilities, and other details to further refine our scope and approaches. We can incorporate the results of this phase into the conceptual model to help us visualize how the inputs, quantitative approaches, and our assumptions will help us answer our exposure assessment questions.

Figure 1. Preparing to Evaluate Exposure



2. SCOPE OF THE EXPOSURE ASSESSMENT

After we have defined the problem our exposure assessment seeks to answer, we then need to define the elements that the exposure assessment will include—in other words, the scope. As part of the scoping process, we will need to identify the stressors, sources of contamination, receptors of interest, exposure pathways, and endpoints to evaluate (U.S. EPA, 2003).

The scope of an exposure assessment can be refined based on legal statutes and regulations that require certain assessments. For example, the Clean Air Act requires assessment of human health and exposure in setting the National Ambient Air Quality Standards. There are a number of regulatory parties from state, to federal, to industry regulators that might have a role in shaping an exposure assessment.

Many other factors can affect exposure assessment scope, including:

- Geographic scale of the problem – singular or multiple source locations; extent of the contamination
- Number of environmental media to evaluate
- Number of environmental stressors and characteristics of stressors – consider metabolites, related compounds
- Receptor types –general population or specific population groups
- Demographic factors – including age, health status, occupational exposures, and receptor dietary patterns
- Level of analysis – screening assessment, iterative refinements, or site-specific analysis

2.1 Geography

The geography for an exposure assessment is dictated not only by the questions to be answered, but also by the source and extent of contaminations and the nearby receptors. The **geographic scale** can range from a small-scale local assessment to a larger regional, national, or international assessment. It can also be influenced by cost and other assessment constraints, which receptor populations are selected, the industries and areas affected, the remediation options available, and any lifetime exposures that might result.

A specific, singular location might be a hazardous-material spill on the freeway or a single leaking underground storage tank. A specific, regional assessment might include multiple locations such as all underground storage tanks in a given area. An example of a national-scale issue is exposure to phthalates in plastics. PCB residues in wildlife could be considered an international problem since they are persistent in the environment and have been distributed across the globe.

2.2 Demographics

To refine the scope of our assessment based on demographics, we must first specify which receptors should be evaluated. A **receptor** is the individual or "group actually or potentially exposed" (U.S. EPA, 2003). We might define a receptor population by location such as a watershed or a city or by other demographic characteristics such as cultural practices, race, economic status, or age. We also need to consider potentially susceptible populations. **Susceptibility** is defined as "an increased likelihood of an adverse effect, often

discussed in terms of relationship to a factor that can be used to describe a human population (e.g., lifestage, demographic feature, or genetic characteristic)."

Some receptor types might be more susceptible to specific stressors than others. For human health exposure assessment, these could include children, women of child-bearing age, the elderly, and people with compromised immune systems. Some individuals might be more highly exposed due to their dietary or activity patterns, such as individuals who eat fish or produce that is contaminated by the stressor. Other individuals might have "differential exposures;" that is, they have historical exposure to the chemical or have lived in an area with higher background levels of particular stressors. Differential exposure might also result from on-the-job or occupational exposure. Sometimes these susceptible populations are called "populations of concern" or "highly exposed populations." We might also need to consider differential preparedness and differential ability to recover (U.S. EPA, 2003).

2.3 Chemicals

The scope of our assessment can be further refined by focusing on specific stressors. A **stressor**, as discussed in EXA 401, is any biological, chemical, or physical entity that can cause or induce an adverse response in a human or ecological receptor. This course will focus on chemical stressors, but we could also evaluate the effects from physical stressors like noise or socioeconomic stressors like access to health care.

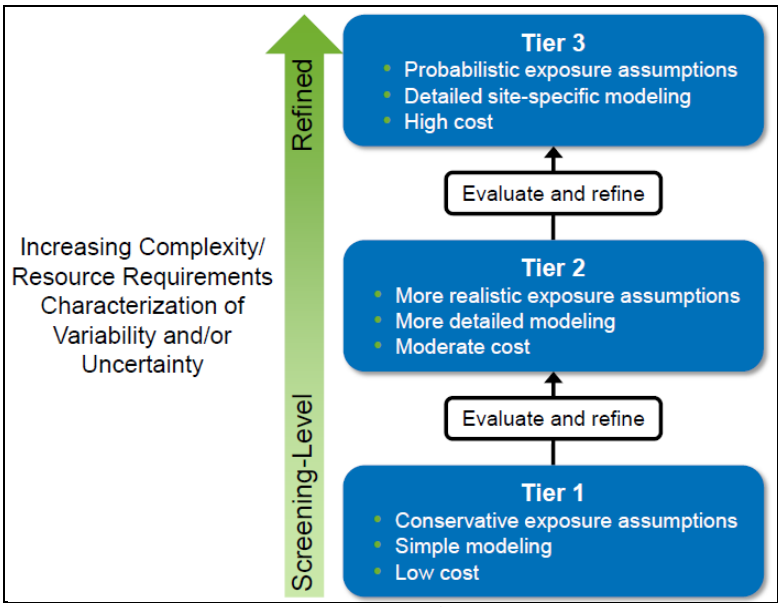
Traditional risk assessment has used a single-stressor approach—likely due to inadequate data for quantifying risks from multiple stressors or limitations in the methodologies available for considering possible impacts from multiple exposures. Scientists now have risk assessment tools and models that allow us to assess multiple stressors. For example, we can now evaluate cumulative and aggregate exposures, population-focused exposures, and risks from exposure to chemical mixtures (U.S. EPA, 2003).

An important consideration related to stressors is their potential interaction with one another. Impacts from stressors can be additive (equal to the sum of the chemical effects), synergistic (the total effect is greater than the sum of the chemical effects), or antagonistic (effects from one chemical cancel the effects from exposure to another). The relationship and interactions of stressors will vary depending on the situation and the stressors of concern.

3. IMPORTANT CONCEPTS IN QUANTIFYING EXPOSURE

After defining the scope our assessment, we need to decide on our analysis approach. The tiered approach to exposure assessment is a step-by-step, iterative process. Using this approach, risk assessors progress from relatively simple to more complex analytical processes as required by the given situation. Individual "tiers" correspond to iteratively more complex, and typically data-intensive, steps in the assessment. At each stage of a tiered exposure assessment, investigators evaluate whether the assessment results are sufficient to support the risk management decisions. The goal of a tiered assessment approach is to strike a balance between the costs of adding detail and refinement to an assessment and the benefits associated with that additional refinement. If the results of a screening assessment using the most conservative assumptions indicate that risks are at or below acceptable levels, more complex analyses will likely be unnecessary (U.S. EPA, 2001). Figure 2 shows a tiered approach developed by EPA for the evaluation of health risks.

Figure 2. Tiered Approach to Exposure Assessment



Adapted from Figure 31-1 in the Air Toxics Risk Assessment Reference Library: Volume 1(2004)

A screening-level exposure assessment is often considered a Tier 1 approach since it produces a quantitative, conservative estimate of exposure using readily available data. Screening-level risk estimates can be used to make comparisons between multiple sites that are being evaluated or to prioritize sites for further analysis. The benefit of this approach is that it is simple to perform and may help indicate whether or not a significant human health or environmental problem exists, potentially preventing unnecessary resources from being devoted to a problem that does not pose a substantial risk. For example, a children's toy might contain phthalates. The concern is that the phthalates could be present in the toys at levels that are hazardous to the children using them especially because children often put toys in their mouths. Based on conservative assumptions and expected use patterns, risk assessors could evaluate the expected exposure and determine whether or not the screening-level risks for specific phthalates are above or below appropriate EPA toxicity reference values. The results of this screening level assessment would allow risk assessors to determine if a higher-tiered assessment should be performed (U.S. EPA, 2009).

Following a screening-level assessment, if we decide that a site or scenario warrants a closer look, we can refine our assessment with:

- More specific measurement data – collect site-specific measured data for environmental concentrations
- Better inputs – refine our exposure parameters to better reflect site-specific conditions or use higher-precision sampling or analysis techniques

- More complex models – move from box model for fate and transport to one that estimates dispersion, deposition and other movement of a chemical in environmental compartments

In many cases, we can conduct a sensitivity analysis of our screening assessment to determine which parameters most affect our exposure estimate so that we don't have to make all refinements at once. We can begin by refining these more sensitive parameters first and then refine others if necessary or as resources permit. In general, an iterative process for refining an exposure assessment is useful and efficient.

3.1 Deterministic Exposure (or Risk) Assessment

Directly related to the level of refinement incorporated into an assessment is whether the results of the assessment are a point estimate or a distribution of possible values. **Deterministic** exposure assessments use **point estimates** (or, single values) to quantify the amount of exposure that is likely to occur for potential receptors. They:

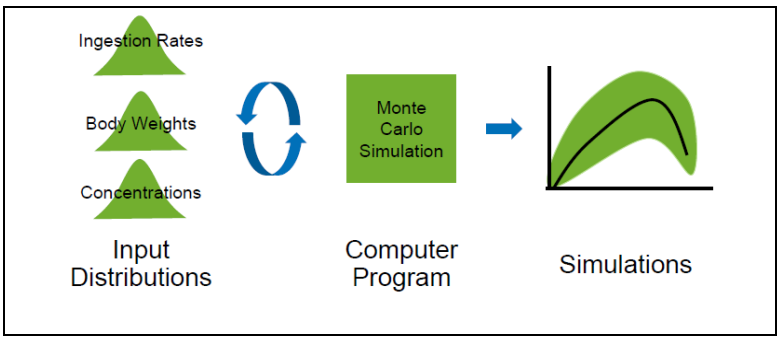
- produce an exposure estimate that is also a point estimate
- estimate of central tendency or high-end exposures within a defined population

Deterministic approaches are used in screening-level assessments partly because of the economical and straightforward nature of the approach. Characterization of uncertainty and variability is limited when using deterministic approaches, but can be increased with multiple deterministic runs. In this way, we can better identify those parameters or aspects of a deterministic evaluation that are uncertain or variable.

3.2 Probabilistic Exposure Assessment

Probabilistic exposure assessment approaches use distributions of data (either probability or frequency distributions) for various parameters to generate a distribution of possible exposure estimates as opposed to a single point. Probability distributions describe the range of values that certain variables might take and estimate the relative likelihood (probability) that any of those values might occur in the given population (U.S. EPA, 2001). So the **probability distribution** helps to account for variability within the population. Guidance on developing and conducting probabilistic assessments is available in EPA's Risk Assessment Guidance for Superfund (RAGS) (1991) and also in EPA's Air Toxics Risk Assessment (ATRA) guidance (2004). Major issues with use of probabilistic approaches are the availability of confirmed distributions and properly accounting for interrelationships between variables.

Figure 3. Illustration of Monte Carlo Simulation



The most popular (but not the only) approach to estimating exposure with probability distributions is the **Monte Carlo simulation** (see Figure 3). A Monte Carlo simulation, named after the casino in Monaco, is "a technique for characterizing the uncertainty and variability in risk estimates by repeatedly sampling the probability distributions of the risk equation inputs and using these inputs to calculate a range of risk values" (U.S. EPA, 2001). Monte Carlo simulations and other

probabilistic approaches can provide estimates of exposure, but doing a probabilistic assessment using Monte Carlo techniques may not be necessary in situations where risk or costs of remediation are low.

Probabilistic methods might require more resources than using a deterministic approach because we have to find distributions for input parameters and possibly use more sophisticated modeling to sample from the distributions to estimate exposure. But Monte Carlo simulations and other probabilistic methods do allow us to better estimate variability in exposure and risk.

It's important to remember that probabilistic simulations are not always necessary. If we can answer our exposure question deterministically, spending time and money to do a probabilistic simulation might not make sense. And just like exposure assessment in general, a probabilistic simulation can be iterative. We can start by investigating a few parameters for which we already have distributions or those parameters that have a big impact on exposure. Then, depending on what we find, we might expand the simulation to other parameters.

We must also remember that the model outputs can only be as accurate or representative as the data that were used to build the model.

3.3 Aggregate and Cumulative Exposure

Aggregate exposure assessment considers combined exposures to a single chemical across multiple routes and multiple pathways. Aggregate exposure assessments often include a summation of all potential exposure pathways. This is a conservative, health-protective approach that assumes that a single person will be exposed to the chemical through all possible exposure pathways (U.S. EPA, 2002). This approach is commonly used in the regulation of pesticides. People can be exposed to pesticide residues in various ways; for example, residues of the same pesticide could be found on multiple foods, in water, and/or in products used in and around the home. EPA conducts risk assessments for pesticide active ingredients by evaluating all of the potential pathways of exposure for pesticide residues to determine the potential risk from aggregate exposure. The relevant pathways of exposure are dependent on the type of pesticide and its registered uses.

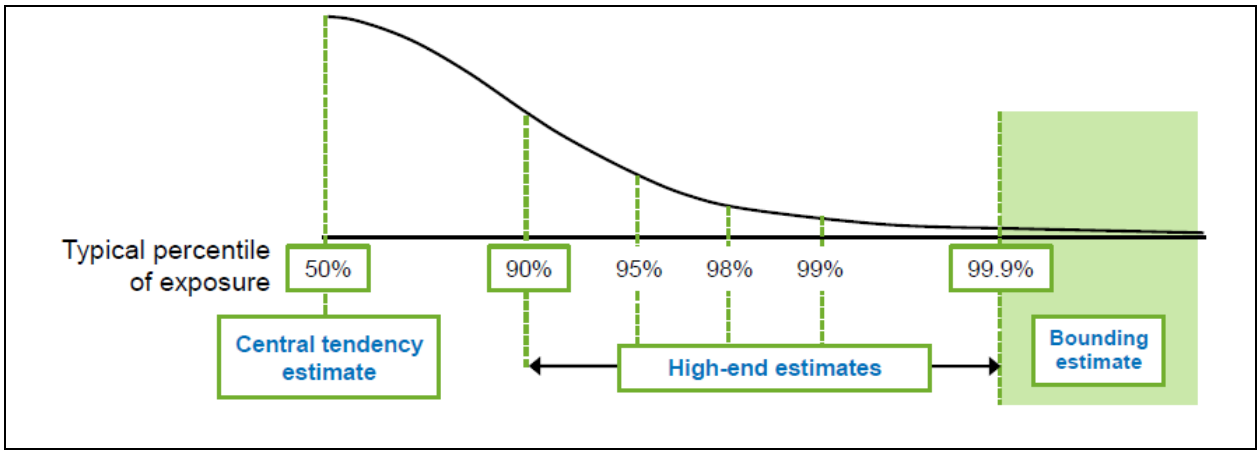
Cumulative exposure assessment is the evaluation of multiple stressors and multiple exposure pathways. In this process, the aim is to assess the cumulative, overall impact on human health of multiple chemicals that act by a common mechanism of toxicity. For example, EPA has conducted a cumulative exposure assessment for the pyrethroid pesticides, a family of chemicals with similar modes of action. EPA considered acute and chronic exposure to residues of pyrethroids in food, water, and other potential residential exposures. EPA also conducts a cumulative exposure assessment when it evaluates multiple chemicals with similar mechanisms of toxicity in their residual risk assessment of air toxics. It is important to remember that the presence of multiple stressors does not necessarily mean that all of those stressors will cause or contribute to an adverse effect. Cumulative exposure assessment considers multiple chemicals and multiple pathways of exposure, but it is not necessarily the simple sum of multiple, aggregate exposure assessments.

3.4 Exposure Descriptors

Selecting exposure descriptors is an important consideration in characterizing and quantifying exposure. Exposure descriptors are estimates for a specific point on the exposure distribution (e.g., mean, median, 95th percentile, maximum). They are based on selected parameter values and can be defined for individual or population exposures. Exposure descriptors are useful when characterizing exposure and can help exposure

assessors communicate with risk managers. Three exposure descriptors are shown in Figure 4 – bounding estimates, high-end or upper-bound estimates, and estimates of central tendency.

Figure 4. Exposure Descriptors



Bounding Estimates

A **bounding estimate** captures the highest possible exposure, or theoretical upper bound, for a given exposure pathway. We often use bounding estimates to perform screening-level assessments.

To calculate an upper bound, we would use the highest intake rates, average body weight, and might assume the highest possible exposure frequency and duration. Each of these values for the input parameters are individually higher than those that probably occur in the actual population and the combination of all of these assumptions is highly conservative. However, if use of these highly conservative assumptions does not result in significant exposures and risk estimates for a particular exposure pathway, then we might be able to eliminate that pathway.

Whatever inputs are chosen, it is important to document the assumptions and the justification for those assumptions.

High-End Estimates

EPA defines a **high-end estimate** as: "An estimate of exposure, or dose level received [by] anyone in a defined population that is greater than the 90th percentile of all individuals in that population, but less than the exposure at the highest percentile in that population."

High-end estimates are expected to be more realistic or more likely to occur compared with bounding estimates and are usually calculated using a combination of high and central inputs. The **RME range, reasonable worst-case exposure,** and **maximum exposure** all account for individuals at the high end of the exposure distribution (at or above the 90th percentile).

- **Reasonable maximum exposure (RME)** – the highest exposure reasonably likely to occur, generally assumed to be in the range of the 90th and 99.9th percentiles [EPA's Risk Assessment Guidance for Superfund (2001)]
- **Reasonable worst-case exposure** – the lower part of the high-end exposure range, which is above the 90th percentile, but below the 98th percentile [EPA Exposure Assessment Guidelines (1992)]

- **Maximum exposure** – the range above the 98th percentile [EPA Exposure Assessment Guidelines (1992)]

As the exposure estimate moves higher within the percentile range, the level of uncertainty increases. These estimates are intended to assess exposures that are higher than average, but still within a realistic or reasonable anticipated range.

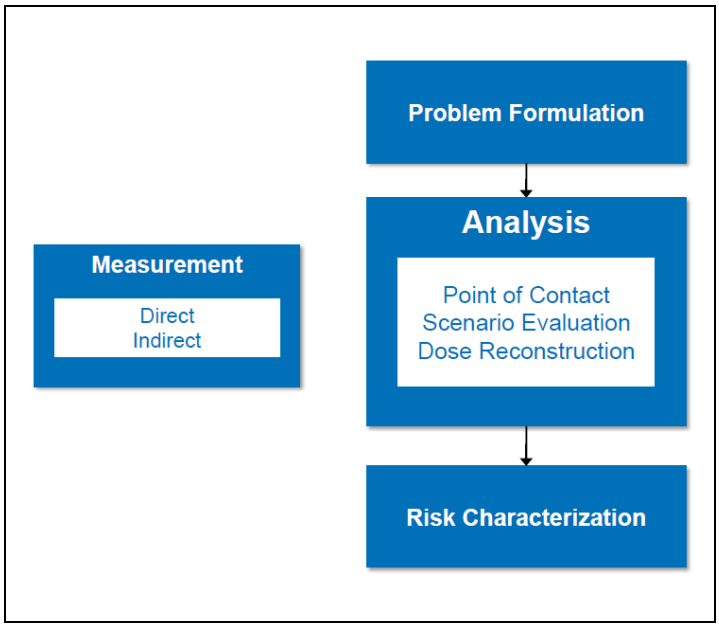
Central Tendency Estimates

The **central tendency estimate** represents the average or typical individual in a population, usually the mean or median of the population distribution. Central tendency estimates (CTEs) could under- or over- estimate exposure in some cases (U.S. EPA, 1992).

- The **arithmetic mean** uses average values for all of the factors that comprise the exposure of interest. This value may not necessarily be representative of a single receptor or group, but falls within the actual distribution and is useful for characterizing exposure for the average population. This value is sometimes called the "average estimate," but terminology varies from assessment to assessment.
- The **median** is another useful descriptor of central tendency, especially when data on the receptor or exposure of interest are skewed as they are in a log normal distribution. This is often called the "typical case," but, the terminology can vary.
- If both the **arithmetic mean** and **median** exposure estimates are available, but vary substantially from each other, it is useful to provide both values to risk assessors to provide greater context about the exposure scenario (U.S. EPA, 1992).

4. THREE APPROACHES FOR QUANTIFYING EXPOSURE

Figure 5. Approaches for Quantifying Exposure



Following scoping and problem formulation, the Exposure Assessment Guidelines (1992) describe three approaches for quantifying exposure during the analysis phase of an exposure assessment. These approaches can be used independently or as supplements to each other to provide comprehensive data regarding exposure or for comparative purposes. These approaches are listed below and are shown in the center rectangle of Figure 5:

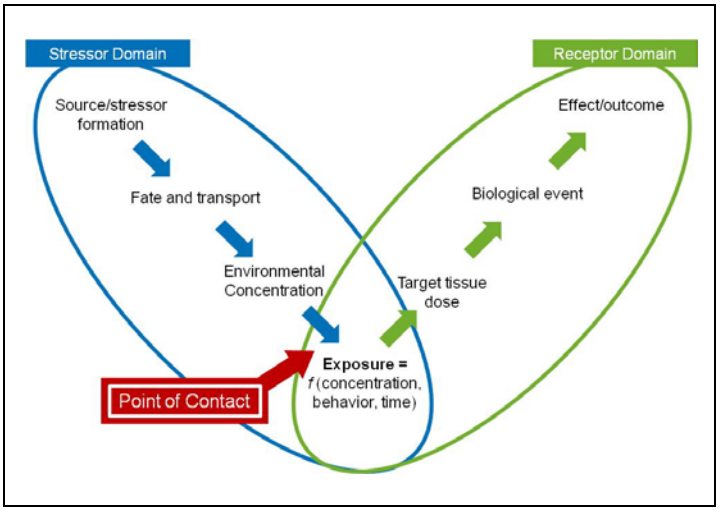
- Measurement of exposure at the **point of contact** (described in Section 4.1)
- Estimation of exposure from **scenario evaluation** (described in Section 4.2)
- Estimation of exposure by **reconstruction of internal dose** (described in Section 4.3)

Each approach uses different sources of information to aid in quantifying exposure. Each can be used to estimate what the individuals were exposed to, how long they were exposed, and, in some cases, the path the substances traveled through the body. We can also quantify exposure in terms of **direct** or **indirect measures**. Direct measures involve sampling or monitoring while indirect measures use methods like models and questionnaires to estimate exposure.

4.1 Point of Contact Exposure Assessment

For a point of contact exposure assessment, chemical concentrations are measured at the interface between the person and the environment, usually through the use of personal monitors. Point of contact exposure assessment was developed primarily for use in occupational monitoring, but more recently, monitors have been developed to measure chemical concentrations that the individuals are exposed to in the given media by sampling the individual's breathing zone, food intake, or water intake. A common example of a point of contact exposure assessment is the radiation dosimeter worn by people that work around radiation including workers in nuclear power plants or in hospital departments where radiation is used. In the continuum between source and effect, the point

Figure 6. Point of Contact Evaluation



of contact approach measures exposure right at the nexus of the stressor and receptor domains (see Figure 6). In other words, it's the point at which the chemical makes contact with the person or organism.

Point of Contact: Strengths and Weaknesses

By using point of contact results we can measure exposures directly rather than inferring from measurements or model results. Point of contact methods, by their nature, are very representative of individual exposures compared with exposure models or population-level assumptions. If the measurement devices used to evaluate exposure are accurate, this approach obtains the most accurate estimate of exposure for an individual over a given time period.

Unfortunately personal exposure monitors and the instruments used to evaluate them can be very expensive and their use may be too costly for some studies. Point of contact methods are route-specific, but are not always source-specific. That is, multiple sources could contribute to the exposure that a person records through their sampling device, so it is not usually possible to determine the source of the chemical. Devices are available for individual substances, but not for all chemicals. To be useful, the point of contact method relies on the accuracy of the mechanical device and the analytical methods used to evaluate the results and the participation of individuals in the study.

Point of Contact: Direct Measurements of Dermal Exposure

There are a number of methods that can be used to measure exposure to contaminants on the skin. They range from simple and inexpensive devices to complex, costly samplers.

Patches were first used approximately 30 years ago to investigate exposure to organophosphate pesticides (Durham and Wolfe, 1962). These Band-Aid or sticker-like patches are placed on the body to collect the contaminant of concern and have been used for a variety of substances, including PAHs, copper oxide, and dusts (Soutar, 2000).

Whole-body dosimeters are intended to measure exposure to the whole body. Examples include badges worn on the clothing, a coverall suit, and full-length cotton underwear (FIFRA SAP, 2007).

Removal methods include rinsing, wiping, and tape stripping to collect the contaminants of concern from the skin to be analyzed.

Optical methods, like fluorescent tracers, involve treating the contaminant of concern with a nontoxic fluorescent tracer and then using video imaging to identify and quantify the points where the contaminant contacts the skin. For example, portable x-ray fluorescence analyzers have been used to detect bromine concentrations resulting from polybrominated diphenyl ethers (PBDE) compounds emitted by consumer products from the homes of a cohort of individuals in the Great Lakes area (Imm et al., 2009). This method has been used as an improvement on existing methods and a way to more accurately characterize human exposure to PBDEs from household products.

Point of Contact: Direct Measurements of Oral Exposure

Duplicate diet studies are a way to measure concentrations of a chemical of concern in the diet. In these studies, individuals collect duplicate samples of all the foods they consume during a given period. The duplicate samples are evaluated by investigators to determine the concentration of chemicals of concern in the

diet and the intake rates of those chemicals. Duplicate diet studies can provide direct measurements of chemical contaminants in food as well as the intake rate of various foods, typically normalized to the body weight of each participant. These studies can also help characterize the total amount of the chemical of concern in different food types.

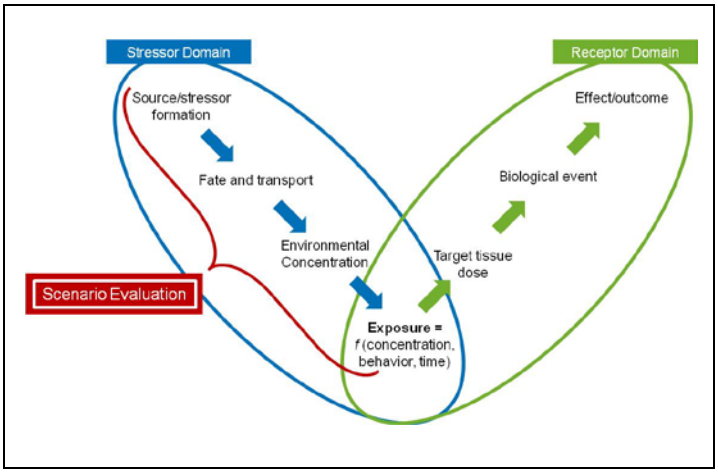
Point of Contact: National Human Exposure Assessment Survey

The National Human Exposure Assessment Survey (NHEXAS) involved 550 people from several different states. The surveys were conducted between 1995 and 1997, and the results were published in 1999. The study was developed by EPA ORD to provide multipathway and multimedia exposure distributions for specific chemical classes. The study was piloted as a conceptual design for exposure assessment with the goal of using similar methods on a larger scale in the future. The aim of NHEXAS was to test the hypothesis that existing data and modeling estimates do not differ from the measurement-based exposure distributions found in the study. The NHEXAS study evaluated exposure to three groups of chemicals: VOCs (including trichloroethylene, benzene, and perchloroethylene), metals (including lead, arsenic, and cadmium), and pesticides (including atrazine, chlorpyrifos, diazinon, and malathion).

In one of the many reports generated from the NHEXAS studies, Clayton and colleagues (1999) reported results of data collected in EPA Region 5 (Great Lakes region). The researchers found that solid food was a major source of arsenic detected in urine, while household lead levels from dust, air, and beverages were all significantly associated with measured blood lead levels. High correlations between tap water and biomonitoring results for lead and arsenic were observed. Moderate correlations were observed for VOCs and personal air sampling.

4.2 Scenario Evaluation for Exposure Assessment

Figure 7. Scenario Evaluation



The scenario evaluation approach estimates exposure indirectly using measured, modeled, or existing data on concentrations in the media; the time of contact; and information about the exposed populations. An exposure scenario is characterized by the elements that determine the exposures, including the exposure setting, characteristics of the chemicals and sources, the exposure pathways and routes, the exposure media, intake and uptake rates, and characteristics of the exposed population. This approach is commonly used in exposure assessment at EPA, especially for characterizing possible future exposures. Exposure scenarios are discussed in detail in EXA 403, so only a few important points are highlighted here.

The scenario evaluation approach encompasses the stressor domain of the source to effects continuum, from the source to the exposure nexus on the left side of Figure 7. Data for stressor concentrations are obtained from media sampling or predicted using fate and transport models. Population characteristics are obtained from interviews with people in the exposed population or are assumed using estimates for the general population or a

particular receptor group. Time of contact can be researched or estimated based what is known about the exposure scenario (U.S. EPA, 1992).

Scenario Evaluation: Strengths and Weaknesses

Scenario evaluation is typically the least expensive of the three exposure assessment methods as it often relies on available data and involves limited equipment and time. Scenario evaluation is well suited to evaluation of the risk consequences from proposed actions. It can also be performed with limited data on the actual exposure situation.

However, the simplification of an exposure scenario using readily available data that are sometimes limited in their scope may lead to a less accurate assessment causing over- or under-estimation of actual exposures. The limited data that are needed to conduct scenario evaluation can result in an estimate with a greater degree of uncertainty.

The data used in scenario evaluation are assumed to be representative of the exposed population. This may be true in varying degrees, depending on the data type and source as well as the situation. It is also assumed that data on chemical fate and transport used in the assessment correspond with the actual fate and transport processes that are occurring.

Scenario Evaluation: Types of Models Used

If we don't have measured concentrations or other exposure data, we will need to use an alternate method to evaluate a scenario. In these cases, a model or a combination of models can be used to estimate the concentrations of a chemical in different environmental media as it moves from the source to the receptor.

Figure 8. Types of Exposure Models

Models	Inputs	Output	Examples
Fate and Transport	• Emission rates • Fate and transport properties	• Pollutant concentrations (mg/m^3, mg/L, or mg/kg) in environmental media	• AERMOD • EXAMS
Exposure	• Concentrations in environments and microenvironments • Exposure factors • Time activity patterns	• Predicted exposures or doses (mg/m^3 or mg/kg-day)	• APEX • DEEM
Combined	• Population characteristics • Dietary exposure • Fate and Transport • Home Chemical Usage	• Population dist. of exposure • Model to measurement comparison	• SHEDS

Fate and transport models like AERMOD and CMAQ estimate chemical concentrations in air. EXAMS models chemical concentrations in surface water. **Exposure models** estimate exposures or doses based on chemical concentration inputs, exposure factors (such as ingestion rates), and, in some cases, time-activity patterns. Time-activity patterns record the activities and locations of individuals through the course of a specific time period. CHAD, EPA's Consolidated Human Activity Database, is perhaps the most familiar EPA resource for time-activity pattern data. Some models exist that **combine** fate and transport modeling with human exposure modeling to estimate the entire source to receptor continuum. Examples of combined models include the SHEDS and LifeLine™ models.

Figure 8 provides an overview of a few of the models discussed by Williams et al. (2010) in their paper "An Overview of Exposure Assessment Models Used by the U.S. EPA."

Scenario Evaluation: Fate and Transport Models

Fate and transport models simulate the movement of and changes affecting contaminants in the environment to predict concentrations of the pollutant in environmental media, including air, soil, surface water bodies (including sediment), and groundwater (that may be a drinking water source).

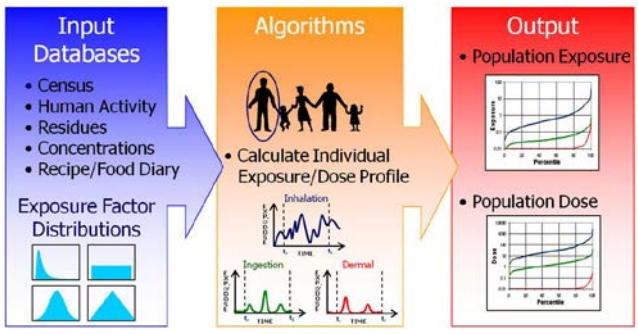
- **AERMOD** (**AMS/EPA Regulatory Model**), a fate and transport model used by EPA, is an air dispersion model that simulates the fate airborne pollutants based on local emission sources. This model may also be used to estimate airborne concentrations at different locations.
- The **EXAMS** (**Exposure Analysis Modeling System**) model, also used by EPA, is a screening-level model that provides estimates of pesticide concentrations in water for use in drinking water or other aquatic exposure assessments. The model accounts for chemical-specific characteristics, and can include site-specific information regarding pesticide application methods as well as the impact of daily weather patterns on treated fields over time.

Scenario Evaluation: Exposure Models

Exposure models are used to predict exposures to individuals or populations through inhalation or multimedia exposure. The model results are based on environmental concentrations, population characteristics, exposure factors, and human activity patterns. As with fate and transport models, the inputs and outputs vary depending on the pollutants, receptors, and spatial and temporal scales used.

- **APEX**, the **Air Pollutants Exposure Model**, estimates population-level exposures to and doses of air pollutants for the general population and sensitive groups at local, urban, and metropolitan scales.
- Another exposure model is **Dietary Exposure Evaluation Model**, or **DEEM™**. This model estimates individual or population-level dietary exposures and doses to pesticide residues in residential settings.
- **LifeLine™** is a probabilistic model for assessing aggregate and cumulative exposures and risks from pesticides and other chemicals. It was developed by a nonprofit organization called the LifeLine Group. The model simulates longitudinal, aggregate exposure to pesticides for each member of a simulated population. LifeLine™ then uses the simulated individuals to create a model population for which exposures are simulated.
- The **Stochastic Human Exposure and Dose Simulation** (**SHEDS**) is a multimedia, multipathway exposure model developed by U.S. EPA's National Exposure Research Laboratory (NERL) in consultation with EPA's Office of Pesticide Programs (OPP) (see Figure 9). It is a physically-based, probabilistic model that simulates aggregate or cumulative exposures over time to estimate human exposure to environmental contaminants via multimedia and multipathway exposure. SHEDS can then be used to estimate dietary and residential exposures based on different types of data and modeling.

Figure 9. SHEDS



SHEDS can help to describe or assess multiple exposure-related issues and questions that include:

- What is the population distribution of exposure in light of variability and uncertainty?
- What are the intensity, frequency, duration, and route of exposure?
- How do modeled exposures compare with measured data?
- How can we assess risk-based uncertainties?
- Which factors, pathways, or media can be targeted with the goal of reducing exposure?

Scenario Evaluation: Combined Models

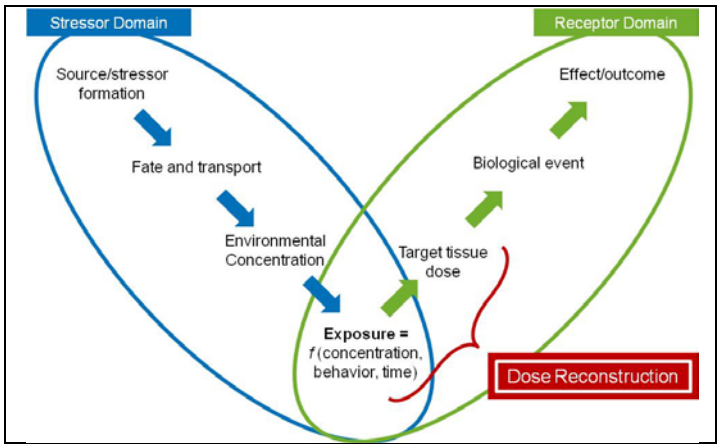
The SHEDS and LifeLine™ models are just two of many combined models used for multimedia and multipathway exposure modeling. A number of popular models, including some of the most-used combined models, are discussed by Williams et al. (2010). A selected few are E-FAST, TRIM, and 3MRA.

- **E-FAST**, the **Exposure and Fate Screening Tool**, is supported by the EPA's Office of Pollution Prevention and Toxics. The E-FAST model provides screening-level estimates of the concentrations of chemicals released to air, surface water, landfills, and from consumer products. As of 2010, version 2.0 of E-FAST was available from EPA.
- **TRIM**, the **Total Risk Integrated Methodology**, is one of the models that Williams et al. (2010) posited as potentially representing the "next generation" (along with 3MRA) of highly-integrated, multimedia models. The TRIM framework was developed by the U.S. EPA Office of Air Quality Planning and Standards and can be used to estimate environmental media concentrations, fate and transport, and population-level exposures and doses for both human and ecological receptors.
- **3MRA**, the **Multimedia, Multipathway, and Multireceptor Risk Assessment**, was developed by the U.S. EPA Office of Research and Development to support the Office of Solid Waste's Hazardous Waste Identification Rule efforts. The model is used to conduct screening-level, risk-based assessment of potential human and ecological health risks resulting from long-term exposure to specific stressors.

Many of the existing exposure models are used primarily for research purposes. To date, there have been limited successful applications of the models for exposure assessment purposes. That said, one practical application of the SHEDS model was in the risk assessment of children's contact with chromate copper arsenate (CCA)-treated wood in play sets. The model results were found to compare well with the results from other CCA exposure assessments, and the results were implemented in the risk assessment of CCA conducted by the EPA's Office of Pesticide Programs.

4.3 Dose Reconstruction for Exposure Assessment

Figure 10. Dose Reconstruction Evaluation



Doses to a specific receptor population are usually not available, but dose can be reconstructed in order to link exposure to potential health impacts using internal indicators of exposure, called **biomarkers**. A **body burden** concentration of a chemical is an example of a biomarker; the body burden simply represents the amount of chemical present in the body. Body burden information can be used to calculate dose in a biological model called a **pharmacokinetic model**. Pharmacokinetic models combine data from physiological and metabolic processes along with body burden data to estimate dose. This reconstruction of the exposure from internal indicator to dose occurs after the exposure has taken place. **NHANES** includes a nationwide biomonitoring study that yields biomarkers of exposure for many different stressors. Data are stratified by age, race, sex, and other factors. Dose reconstruction allows us to estimate exposure based on information from an effect or outcome or a target dose (see Figure 10).

Dose Reconstruction: Strengths and Weaknesses

Biomarkers can provide proof of exposure to a compound or its metabolites. In addition, biomarkers provide valuable information about past exposures and potential health impacts that may result from those exposures. With an appropriate model, dose reconstruction has the potential to give the most accurate estimate of total exposure of the three methods discussed.

Dose reconstruction does not tell us about the exposure pathway involved; biomarkers are not source specific. Biomarkers are not always directly related to source chemicals because multiple chemicals may have the same biomarkers. Models are not always available that link dose with exposure for the stressor of concern. When models are available, we have to accurately parameterize them based on measured or experimental data. Biomarkers may indicate exposure to metabolites rather than the parent compound. Sampling for biomarkers might not always be possible, and databases with biomonitoring data may have to be used. Finally, due to the high costs of sampling and evaluation, this method might not be feasible.

5. SUMMARY OF EXPOSURE QUANTIFICATION APPROACHES

Figure 11 below summarizes the available approaches for quantifying exposure.

Figure 11: Exposure Quantification Approaches at A Glance

Approach	Key Points	Examples
Point of Contact	Quantifies exposure as it occurs, at the interface between the person and the environment. Representative of individual exposure. Most accurate method of quantifying exposure. Can be expensive; not source-specific; relies on accuracy of the device used for sampling.ey Points	Whole-body radiation dosimeters Patch or tape stripping measurements Duplicate diet studies
Scenario Evaluation	Scenario that combines data on chemical concentration, time-of-contact, and population characteristics. Elements that determine exposure: setting, chemical characteristics, sources, exposure pathways and routes, intake and uptake. Can be economical; well-suited to evaluating proposed actions; can be done with limited data.ints	Fate and transport models: AERMOD, CMAQ Exposure models: APEX Integrated models: 3MRA
Dose Reconstruction	Estimate of exposure from dose, based on monitoring. Dose estimated using biomarkers of exposure. Can provide unambiguous proof of exposure, may give most accurate estimate of external dose. Does not provide exposure pathway, amount, or source. Data not always available, may be expensive.ints	Biomarkers of exposure: NHANES

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