United States Environmental Protection Agency

Exposure Assessment (EXA)
Course Series

Developing Exposure Scenarios and Calculating Dose

Reading Packet

EXA 403

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

EXA 403: Developing Exposure Scenarios and Calculating Dose

READING PACKET

Exposure Assessment (EXA)
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EXA 403: Developing Exposure Scenarios and Calculating Dose

Exposure scenarios are sets of facts, assumptions, and inferences about how exposure takes place that aid the exposure assessor in evaluating, estimating, or quantifying exposure. This course will provide participants with the necessary tools for developing assessment-specific exposure scenarios. Factors that will be considered include: the source(s) of contaminant release, identification of contaminants, transport of contaminants from source to site of exposure, exposure media that are impacted, potentially exposed populations, and exposure routes and pathways. This course will help participants hone their skills in scenario development and will introduce them to some standard scenarios used in EPA program offices and/or in published exposure assessments.

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1. INTRODUCTION AND BASIC CONCEPTS

In EXA 401 and 402, the process for conducting an exposure assessment and the key concepts of exposure assessment, including dose, were introduced. This course introduces exposure scenarios, which are used as a framework to characterize and quantify exposure and dose.

1.1 Exposure Concepts

EPA defines an exposure scenario as, **"A set of facts, assumptions, and inferences about how exposure takes place that aids the exposure assessor in evaluating, estimating, or quantifying exposure"** (U.S. EPA, 2004a). The elements used to develop an exposure scenario dictate the terms of exposure to a substance for a selected individual or population. These elements include exposure setting, source(s) of contamination, impacted media, chemicals of concern, exposure pathways, potential receptors, and characteristics of the potentially exposed population. A risk assessor must consider information on each of these elements when developing an exposure scenario.

So why do we develop exposure scenarios? Exposure scenarios help the exposure assessor visualize how exposure(s) might take place, which is key to identifying the data required to conduct the assessment (U.S. EPA, 1992). Exposure scenarios provide a framework for quantifying exposure, dose, and risk by following the chemical from the source of its release into the environment (through various pathways including air, soil, water, and food) to the potential receptors. During development of exposure scenarios, the risk assessor should consider specific types of exposure, such as exposure to susceptible populations like children.

Figure 1. Example Exposure Setting

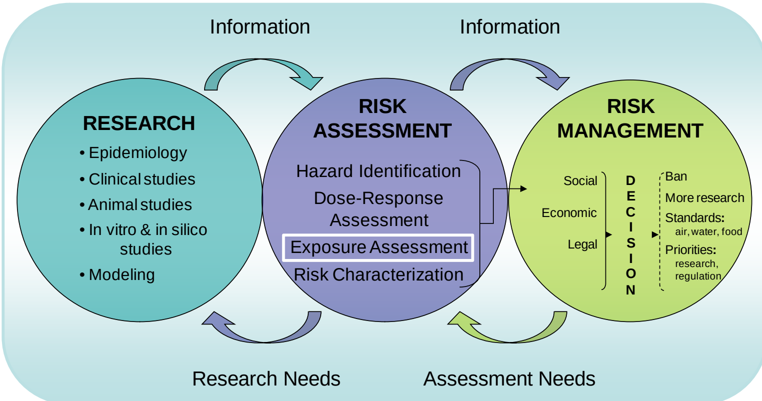
The image in Figure 1 on the next page depicts an example exposure setting—a recreational park where children and adults play with a factory in the background. The factory could be a potential source of contamination, and the populations of concern are the children and adults who use the park.

Potential exposure pathways for human receptors using the park include:

- Inhalation of factory emissions;
- Dermal contact with surfaces at the park where contaminants have deposited; and/or
- Inadvertent ingestion via hand-to-mouth and object-to-mouth activity (especially for young children).

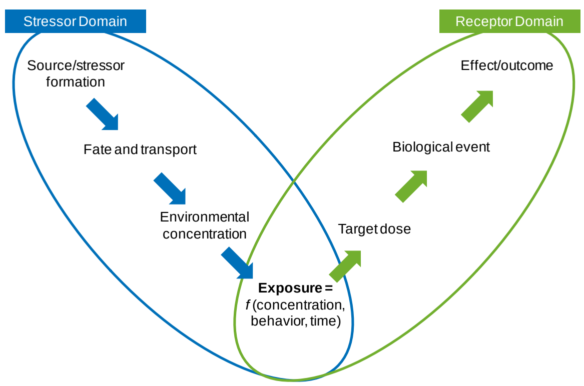
This exposure scenario defines a possible e source of exposure, potential populations exposed, and the activities in which the population are engaged that might facilitate exposure to chemicals of concern.

Figure 2. Risk Assessment Paradigm



In EXA 401, exposure assessment was discussed as one of the four basic components of the risk assessment paradigm, as shown in Figure 2. Risk is quantified by combining exposure and toxicity, and an exposure scenario provides a framework for estimating the exposure component by examining source of chemical release into the environment, potential exposure pathways (e.g., soil, water), and routes of exposure for potential human receptors (e.g., dermal, ingestion, inhalation).

Figure 3. Source-to-Effect Continuum



Adapted from Williams et al. (2010)

Figure 3 illustrates exposure's position within the source-to-effect continuum of exposure assessment:

→ release of the chemical from a source →

→ transport through environmental media (e.g., air, water, soil) →

→ human exposure via inhalation, ingestion, or dermal routes →

→ effects that occur from exposure

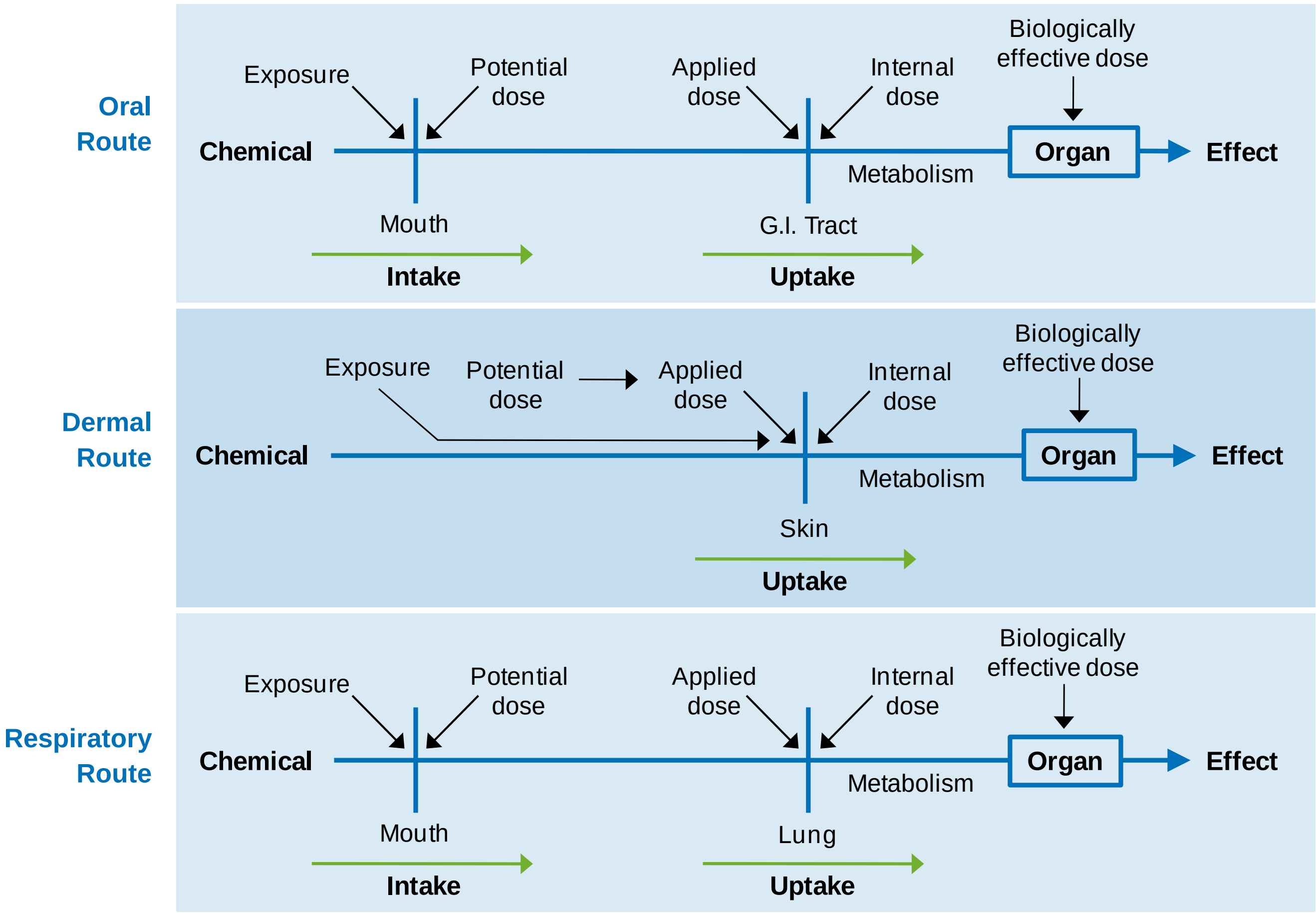
(Williams et al., 2010).

1.2 Dose Concepts

Dose provides a measurement of exposure. Figure 4 depicts several aspects of dose by three routes of exposure (oral, dermal, inhalation). Key terms are briefly discussed below (U.S. EPA, 1992).

- **Potential dose** is the amount of chemical ingested, inhaled, or in a material applied to the skin. It is the potential amount of the chemical that could be absorbed if the chemical were 100% bioavailable. This amount is analogous to the administered dose in a dose-response experiment.
- **Applied dose** is the amount at an absorption barrier (like the gastrointestinal tract, lungs, or skin) available for absorption.
- **Internal dose** is the amount of a chemical that has been absorbed and is available for interaction with biologically significant receptors.

Figure 4. Illustration of Dose



Adapted from U.S. EPA (1992)

In a quantitative risk characterization, a comparison of the dose estimate for a particular chemical and its toxicity value are used to develop a quantitative estimate of risk for that chemical. In order to carry out this calculation, the dose units need to be compatible and comparable to the units of the toxicity value. For example, in the case of inhalation exposure, a cancer risk toxicity value known as "unit risk" has units of $(\mu g/m^3)^{-1}$ and is defined as an upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 $\mu g/m^3$. To assess cancer risk from inhalation when there is a unit risk value, the dose units must also be units of concentration. Cancer risk is then calculated as the product of a chemical's air concentration and its unit risk value. Regardless of what "kind" of risk is being calculated (e.g., oral, inhalation; cancer, noncancer), the units must cancel out in the calculation because risk is unitless.

Cancer risk is defined as "the probability of contracting (not dying from) cancer during a lifetime. A risk level of 1 in a million implies a likelihood that up to one person, out of one million equally exposed people would contract cancer if exposed continuously (24 hours per day) to the specific concentration over 70 years (an assumed lifetime). This risk would be an excess cancer risk that is in addition to any cancer risk borne by a person not exposed to this chemical." (Definition from glossary for the National-Scale Air Toxics Assessment at http://www.epa.gov/ttn/atw/natamain/gloss1.html.)

For noncancer effects, a **hazard quotient** is used. The hazard quotient represents "the ratio of the potential exposure to the substance and the level at which no adverse effects are expected. If the hazard quotient is calculated to be equal to or less than 1, then no adverse health effects are expected as a result of exposure. If the hazard quotient is greater than 1, then adverse health effects are possible. The hazard quotient cannot be translated to a probability that adverse health effects will occur and it is unlikely to be proportional to risk. It is especially important to note that a hazard quotient exceeding 1 does not necessarily mean that adverse effects will occur." (Definition from glossary for the National-Scale Air Toxics Assessment at http://www.epa.gov/ttn/atw/natamain/gloss1.html.)

The dose equations below show the importance using the appropriate units in the calculation of dose, and provide a foundation for exploring the required components of an exposure scenario (U.S. EPA, 1992).

$$\text{Potential Dose} = \frac{C \times IR \times CF \times ED \times EF}{AT \times BW}$$

$$\text{Absorbed Dose} = \text{Potential Dose} \times AF$$

$$\text{Absorbed Dose} = \text{Internal Dose}$$

Where:

Term	Definition
C	Contaminant Concentration
IR	Intake Rate
CF	Contact Fraction
ED	Exposure Duration
EF	Exposure Frequency
AT	Averaging Time
BW	Body Weight
AF	Fraction of Potential Absorbed Dose

The first equation provided above is a simplified equation for calculating potential dose. Absorbed dose is calculated then by multiplying the potential dose by the fraction of the potential dose absorbed, or AF. The absorbed dose is equivalent to the internal dose (U.S. EPA, 1992). In order to perform a quantitative risk assessment, these parameters must be defined for each exposure scenario. All parameters must be expressed in consistent units, and in some cases unit conversion factors will be necessary. Final units of potential and absorbed dose will be mass of contaminant per unit body weight over time (e.g., mg/kg-day).

These parameters in the dose equation can vary over time.

- Concentration (C)
- Contact fraction (CF)
- Intake rate (IR)
- Body weight (BW)

Concentration is the exposure concentration of the substance of interest. This can be a measured or modeled value usually presented in units of mg/m^3-air, mg/kg-food, or other similar units.

Contact fraction represents exposure to contaminated vs. uncontaminated media. For example, a contact fraction of 1.0 means that all of the food consumed (represented by an intake rate) is contaminated. In this case, the contact fraction term does not need to be explicitly included in the dose equation. A contact fraction of 0.5, however, means that half of the total intake is contaminated, and therefore that the intake rate must be multiplied by the contact fraction to find the amount of contaminated material ingested. Because it is a fraction, CF has a value of 1.0 or less and is unitless.

Intake rate is the rate at which the individual takes in a contaminated medium. This might be an ingestion rate, a dermal absorption rate, or an inhalation rate. Intake rate is expressed in units of mass or volume per unit time, such as mg/day or L/day. Recommended values for intake rates of specific foods such as fruits, vegetables, meat, and fish are provided in EPA's *Exposure Factors Handbook* (U.S. EPA, 2011). Exposure factors are discussed in greater detail in EXA 406.

The **body weight** of the individual is also included so that the dose is normalized to that value. Sometimes the intake rate is already normalized to body weight. For example, an oral intake rate may be provided in units of mg-chemical per kg-body weight. In these cases a separate term for body weight is not necessary. Body weight is typically expressed in kilograms. EPA's recommended body weight value for an adult is 80 kilograms (U.S. EPA, 2011).

Temporal factors are also included in the dose equation. These factors are expressed in units of time, which differ from factors that vary over time. These temporal parameters in the dose equation are provided below.

- Exposure duration (ED)
- Exposure frequency (EF)
- Averaging time (AT)

Exposure duration is the amount of time that an individual or population is exposed to the chemical being evaluated. The ED can be given in minutes, hours, days, or years. For example, to calculate the lifetime average daily dose, it is important to know how many years over the course of a lifetime the individual or population is exposed. For an occupational exposure, a reasonable assumption might be 20 years.

Exposure frequency refers to the frequency with which the exposure occurs. Common EF units are days per year (e.g., 350 days/year) or events per day. Consider how the EF would differ if a population is exposed to a contaminant in the water from swimming versus showering. The EF for the swimming scenario might be approximately 10 days per year, while the EF for the showering scenario might be close to 365 days per year.

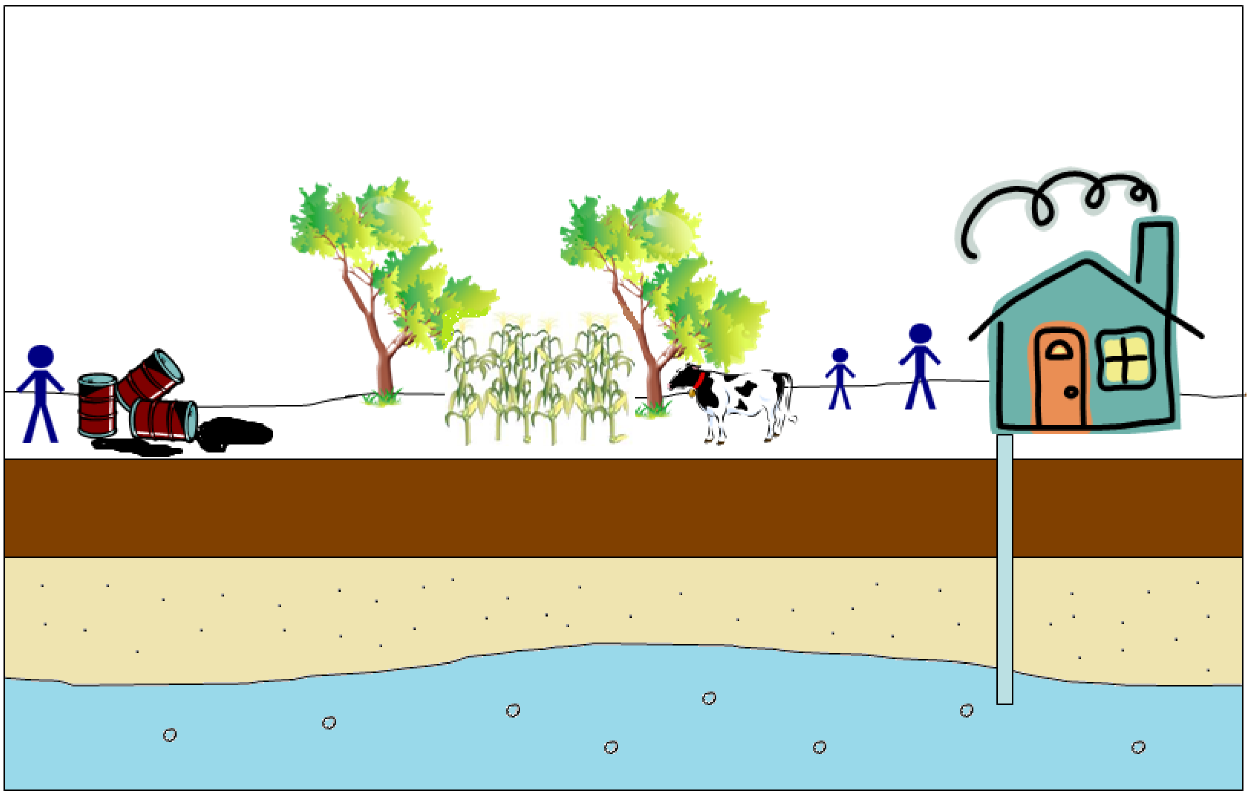
Averaging time is the amount of time over which exposure is averaged. This value must be equal to or larger than the ED and have the same units as the ED. The AT must be consistent with the nature of the potential effects (i.e., the hazard) associated with the chemical of interest. This can include effects associated with short-term or acute exposures up to chronic lifetime exposures. For example, to calculate the lifetime average daily dose for a chemical, as is the case for cancer risk, the AT would be the number of years that the exposed individual is expected to live, regardless of how many of those years the individual is exposed to the chemical. Historically, the most common assumption for this term has been 70 (U.S. EPA, 2011). For noncancer effects, the exposure assessor might set the AT equal to ED.

2. CHARACTERISTICS OF AN EXPOSURE SCENARIO

This section discusses the important characteristics or elements of exposure scenarios.

Figure 5 below illustrates the setting for an example exposure scenario. This exposure scenario will provide the framework for estimating potential human exposure (including dose, if appropriate).

Figure 5. Example Exposure Scenario



The following assumptions could be made after considering this image.

- Source of the exposure: spill from a pile of waste drums
- After the chemicals are released into the environment, they could:
  - Volatilize into the air
  - Seep into the soil
  - Seep into groundwater
- People could be exposed to the contaminants in the following ways:
  - Inhaling contaminated air
  - Drinking contaminated groundwater
  - Ingesting contaminated soil
  - Eating contaminated crops and animals

Note also that there are no means shown in this image by which to contain the spill, and the spill occurred in proximity to a residential area. The characteristics that should be considered in characterizing this exposure scenario are discussed in more detail below.

2.1 Exposure Setting

Exposure setting is the physical setting where the exposure occurs. By identifying the exposure setting, the exposure assessor defines the boundaries of the site and determines the scope and geographic scale of the assessment (U.S. EPA, 1992). Considering the information provided in Figure 5, the following characteristics of the exposure setting are important in determining how the population in this example might be exposed.

- The primary source of contaminant release is the drum spill.
- The spill happened in an open uncontained area.
- The spill occurred near farming and livestock.
- Humans and animals exist in this area in close proximity.
- Prevailing winds might affect the direction of any fumes released from the spill.
- Groundwater is the water source for the residence in the figure.

2.2 Chemicals of Concern

The chemicals of concern are the chemicals or pollutants to which an individual or population is exposed. It is important to know as much as possible about the chemicals of concern because chemical characteristics help assessors understand chemical transport in the environment and predict interactions with exposed individuals/organisms and environmental media.

Examples of critical physicochemical properties include:

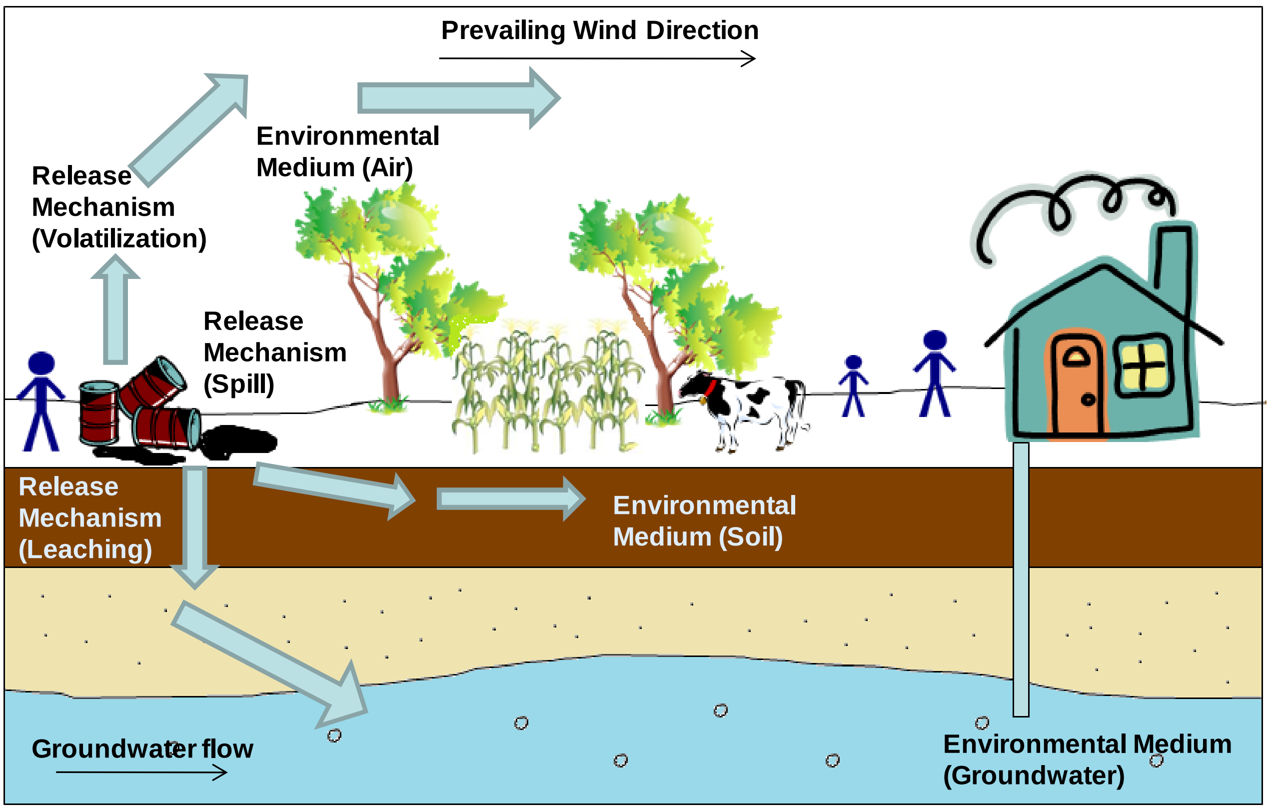
- Molecular weight
- Physical state,
- Vapor pressure
- Solubility

The assessor must also consider the source-to-receptor concept. It is important to understand the source of the exposure and how much has been (or is being) released, the pathway that the chemicals of concern take through the environment to the exposed individuals/population (receptors), and the characteristics of receptors. The amount of chemical that has been or is being released will affect the magnitude of the exposure and dose to the receptors. The location of the release is also important—for example, if the chemical is released in a contained or uncontained area. This example exposure scenario would be very different if the spill had occurred in a landfill where there are controls in place to contain leaching. Other aspects to consider—how quickly chemicals are being released to the environment, the quantities of chemicals that have been or will be released, and the concentrations and potential interactions of the chemicals (U.S. EPA, 1992).

2.3 Fate and Transport

Upon its release into the environment, a chemical can be transported and transformed. For this example scenario, the potential fate and transport of the released chemicals is evaluated. Because the exposure occurred in an open and uncontained area, there is potential for chemicals to volatilize or become airborne as particulates and settle on nearby soil, surface water, and plants. Figure 6 shows that there is a prevailing wind, which means that the exposures may occur downwind of the site. Concentrations of the chemicals will likely vary in the environment depending on the distance from the source. The chemicals have also seeped into the soil and leached to groundwater, which could be the primary source of drinking water for this nearby residential area.

Figure 6. Example Exposure Scenario: Fate and Transport



2.4 Environmental and Exposure Media

If humans are exposed to contaminated media (e.g., soil, groundwater), these "environmental media" are now referred to as "exposure media." Chemicals can be transferred between media. Many chemicals bioaccumulate, or are taken up, into organisms. They deposit onto soils and vegetation (such as grass) and bioaccumulate in terrestrial animals.

"Direct" exposures to humans might include inhalation of released contaminants or ingestion of or dermal contact with contaminated soil. Consumption of impacted animal foods would be an example of "indirect" exposures; for chemicals that are long-lived and bioaccumulate in the environment, the indirect exposure pathways can be substantially more important than the direct exposure pathways (U.S. EPA, 1998).

In some exposure scenarios, a contaminated exposure medium might be considered the source of contamination. For this example scenario, the source of contamination is the chemical spill from the ruptured drums. It is possible that the drums and spill contents will be “cleaned up” thereby removing the original source. However, in some cases, the cleanup plan does not completely remove the spilled chemicals from impacted media. If the soil and ground water were contaminated but were not remediated or removed from the site, these media could now be considered the primary sources of contamination.

2.5 Exposure Pathway and Exposure Route

The exposure pathway is the physical course within the environment that a chemical takes from the source of the chemical to the exposed individual or population (U.S. EPA, 2004a). The exposure pathway reflects the physical and chemical fate and transport and transformation processes that occur, which were discussed in the Section 2.3.

An exposure route is the way that a chemical enters an individual or population after contact (U.S. EPA, 2004a). The difference between an exposure pathway and an exposure route can be confusing. Potential exposure pathways for this example scenario are described below.

- The chemicals volatilize or become airborne as particulates where they are carried by wind and can be deposited on soil, surface water, and crops.
- The chemical seeps into soil and groundwater, which may be used as drinking water.

Exposure routes for this example scenario might include:

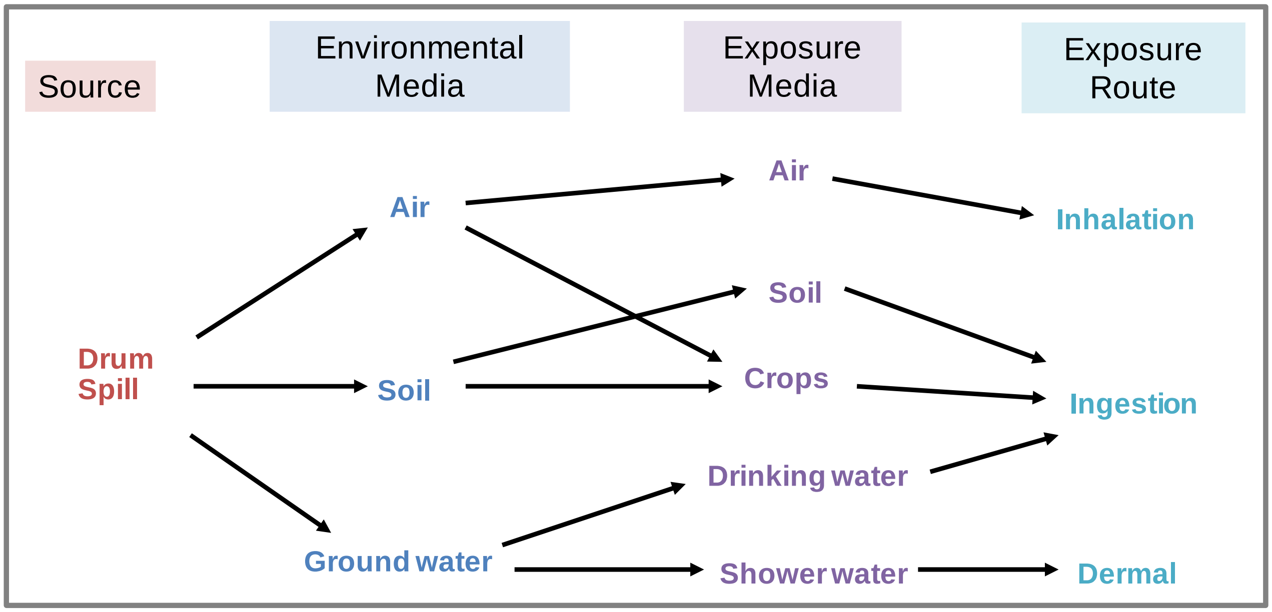
- Ingestion
- Inhalation
- Dermal contact

There are numerous exposure pathways in this scenario and some (but not all) of them are captured in the conceptual diagram in Figure 7. As noted previously, chemicals could be transported via air and deposit on soil, surface water, and plants. It could be transported by erosion, runoff, and other surface movements. This scenario warrants consideration of food chain impacts. Livestock such as cows could eat contaminated plants or drink contaminated water, and humans could then eat the cow or drink the cow’s milk and be exposed indirectly. The substance could also seep into the soil and from there groundwater.

Possible exposure routes should also be considered here. Because the substance is volatile, it could be inhaled or deposited in surface water and then ingested. It also seeps into groundwater and soil, and groundwater could be ingested. Contaminated plants and animals could also be ingested. Humans could also be exposed to contaminated soil via incidental ingestion or dermal contact.

Though Figure 7 only depicts what appear to be “outdoor” exposures, “indoor” exposures also occur through track-in of dust and soil, or indoor inhalation of air through open windows or volatiles from showering.

Figure 7. Example Exposure Scenario: Exposure Pathways and Routes



2.6 Intake and Uptake Rates

After constructing an exposure scenario that describes potential exposure pathways, receptors, and exposure routes, it is then important to consider intake and uptake rates for receptors.

When developing an exposure scenario, the assessor must consider the rate at which contaminated substances are contacted via ingestion, inhalation, and dermal routes by an individual or population exposed to the contaminated media. This rate of contact with a contaminated medium is called **intake rate**. The **uptake rate** then refers to the rate at which the chemical crosses an absorption barrier after contact has been made (U.S. EPA, 2004a).

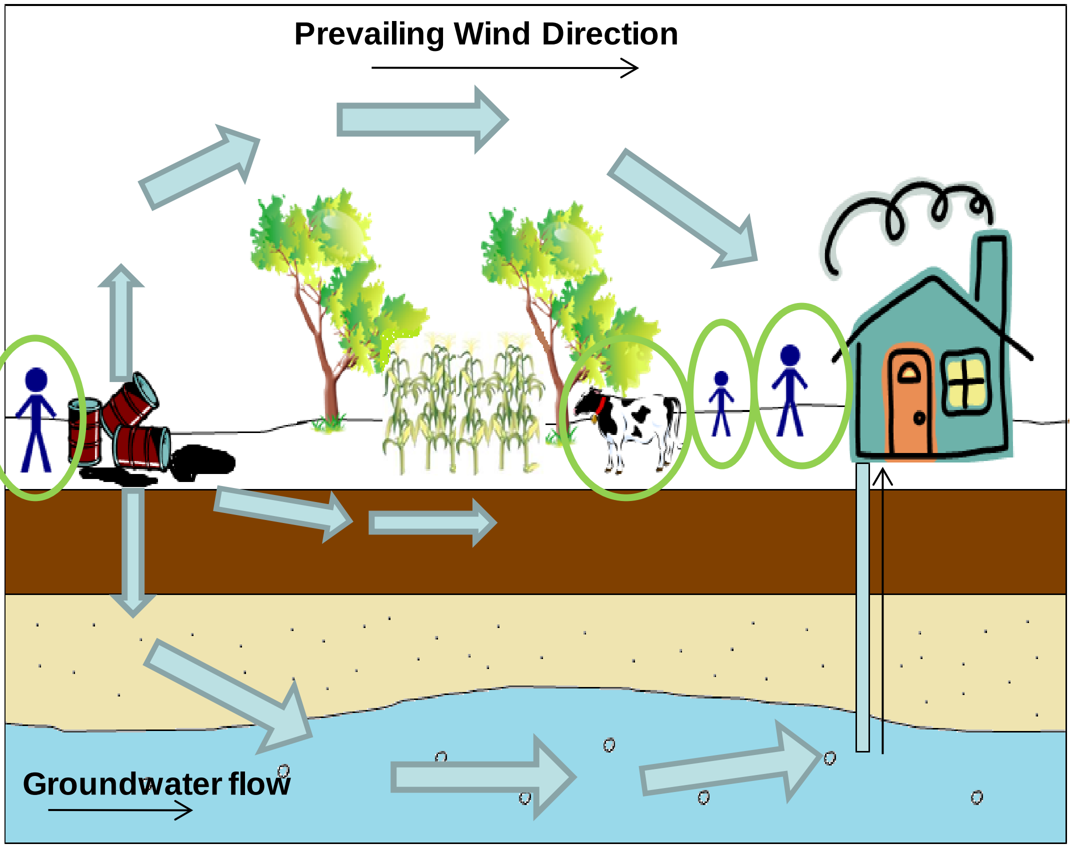
- For **ingestion**, the intake rate is simply the amount of food or water (or other beverage) containing the chemical that an individual ingests during a specific period of time.
- For **inhalation**, the intake rate is the individual's inhalation rate in volume of air inhaled per unit time. Inhalation rates will vary according to activity level, age, physiological properties of the individual, and other elements.
- For **dermal exposures**, the intake rate is the rate of dermal contact between the individual and the chemical. Elements to consider include skin surface area, adherence of contaminated media to the skin, time during which dermal contact occurs, and other factors.

The internal (or absorbed) dermal dose is determined by the rate at which the chemical is absorbed. Along with factors just mentioned, this is a function of contaminant properties. The most conservative assumption is 100% absorption, and this is often assumed for inhalation and food ingestion exposures. For contaminants that tend to be tightly sorbed to organic matter (i.e., exhibit high K_{ow}) such as PCBs and dioxin, the rate of absorption is often assumed to be less than 100%. For soil ingestion, for example, an absorption rate of 30% might be used for these contaminants. For dermal contact with dust or soil, an assumption of 3% has been used for these highly sorbed organic contaminants (U.S. EPA, 2004b, 1989).

2.7 Receptors of Concern

The receptors of concern are the individuals or population potentially exposed to the chemicals. Receptors could include humans and/or animals and might be one or multiple organisms (see Figure 8). The focus of this course is on human exposures.

Figure 8. Example Exposure Scenario: Receptors of Concern



The physical characteristics of the individuals or population exposed, including age, body weight, and skin surface area, are critical because these can affect calculation of dose. The activities in which the receptors are engaged as well as the location of the exposed individuals are also important factors. For example, activity patterns could affect respiratory rate, which in turn can affect how much of a substance is inhaled. Proximity of the receptors to the source of the chemical and other location factors (e.g., whether someone is upgradient or downgradient of the site) could also affect the amount of the chemical to which individuals are exposed.

Below are some observations about the receptors in this example exposure scenario.

- Receptors include humans and animals.
- Individuals are exposed in occupational and residential settings.
- Proximity of receptors to the source of the release varies.

These observations are important in developing exposure scenarios since they can help identify and parameterize relevant scenarios. It is important to identify characteristics of the receptors of concern that might affect exposure opportunities (e.g., resident versus site worker). Residents could include individuals of all ages who may be exposed for long periods of time. Workers would most likely include only individuals over the age of 18 years and their exposure frequency and durations might be much shorter.

Sensitive receptors such as **infants**, **children**, and **elderly adults** also need to be considered in an exposure assessment. These populations may experience greater effects for a given dose than individuals in the general population. Children's exposure is different than adults' exposure. Children have important physiological and behavioral differences. Compared with adults, children may be more exposed to some environmental contaminants because they consume more of some kinds of foods and water per unit of body weight, have a higher ratio of body surface area to volume, and have different activity patterns. For example, children may have more opportunities for incidental ingestion of chemicals via hand-to-mouth and object-to-mouth activities (U.S. EPA, 2008). Infants also have unique exposure opportunities as some may be exclusively breastfed up to the first year of life; different chemicals partition more or less effectively to human breast milk.

If the chemical of concern is in consumer products, it is important to identify the characteristics of the **consumers** using the product. Some products, such as toothpaste, are used by both genders, almost all age groups, and across racial, cultural, and socioeconomic groups. Other products, such as cosmetics or infant toys, are used by specific age groups or genders.

Fisherman and subsistence farmers may be disproportionately exposed to some chemicals. They may eat more of the fish or crops that they catch or grow, so they would experience disproportionate exposures to chemicals in those fish or crops. The differences in intake rates among these different populations will be discussed in greater detail in EXA 406.

Specific **racial, ethnic, and socioeconomic groups** might also be disproportionately exposed to certain chemicals due to differences in diets and cultural activities.

Another consideration is a receptor's **susceptibility** to chemicals (extrinsic susceptibility such as health status rather than intrinsic susceptibility such as life stage discussed above). Individuals with pre-existing diseases could be more susceptible to pollutants; for example, an individual with asthma might be more susceptible to air pollutants.

2.8 Common Exposure Scenarios

Ingestion scenarios are intended to cover routes by which bioaccumulative chemicals might end up in the food chain. However, not all ingestion scenarios will include chemicals that bioaccumulate. Ingestion of articles grown on a farm or in a home garden, including produce, or livestock; and animal products, such as dairy products (e.g., milk, cheese) and eggs are all ways that humans could be exposed to harmful substances in the environment (U.S. EPA, 2004a). Drinking water could also be a potentially contaminated medium if an individual obtains drinking water from a well at the site, or if the surface water source feeds into the public water supply. Fish ingestion is a commonly-evaluated scenario; persistent bioaccumulative chemicals can accumulate in fish following deposition to the water body and watershed and transfer to fish via diet and direct transfer from the water.

Sometimes, an incidental ingestion scenario will be relevant, such as consumption of dust or surface soil. Another example of an incidental ingestion scenario that is particularly relevant to children is ingestion of residues on the surface of a toy or other object. The residue can be transferred to the hands and ingested either via hand-to-mouth or object-to-mouth activity.

Breast milk consumption can also be important for some chemicals such as PCBs or dioxins, which readily bioaccumulate in fat and are transferred in human milkfat to a nursing infant. Other important exposure scenarios included by EPA include subsistence farmers, home gardeners, subsistence fishermen, and recreational anglers.

Inhalation exposure can also be relevant for either outside or indoor air (or both), depending on the source and nature of the pollutant (U.S. EPA, 2004a). Characteristics of the exposed individual and population are important to define for inhalation scenarios because they determine intake rate. Individuals in an occupational setting are often assumed to be working harder than residents and so might be assumed to have a higher inhalation and thus intake rate. Personal characteristics also dictate activity patterns, which determine where a person is located and the intensity of the activities the individual is engaged in.

Dermal exposure can be important for some chemicals and exposure settings. Example scenarios involving dermal exposure include contact with:

- contaminated soil or water by residents (such as children while playing)
- contaminated soil in occupational settings (e.g., by workers at a hazardous waste remediation site)
- products that contain chemicals of interest, such as building materials or consumer products.

For dermal exposure scenarios, the fraction of chemical absorbed through the skin is important. In some cases, there will not be useful data on absorption, and an appropriate approach might be to assume complete (100%) absorption as a first approach. This approach, however, can result in very high exposures (e.g., if the concentration of chemical in the contaminated medium is high), so it's important to be aware of uncertainty regarding absorption efficiency.

EPA often considers a subsistence farmer and home gardener in standard dermal exposure assessments because of the potential that these individuals will come into contact with contaminated soil (U.S. EPA, 2004a).

2.9 Uncertainty and Variability

Variability and uncertainty should be considered when constructing an exposure scenario and when characterizing results of an exposure assessment. As previously discussed, it is important to identify the characteristics of receptors when developing an exposure scenario. Characteristics such as body weight and age will vary within a population. For example, a particular exposure scenario may be constructed around "children" aged 1–6 years, but even within this well-defined smaller age range, there are differences in body weight.

Variability refers to true heterogeneity or diversity (U.S. EPA, 2010), and in the context of exposure assessment, inter-individual variability, intra-individual variability, spatial variability, and temporal variability must all be considered (U.S. EPA, 1992). For example, an individual's body weight will vary over the course of his or her lifetime, and body weights will vary across individuals within a population. Similarly, chemical concentrations will vary over time and by location.

Uncertainty is defined as a lack of knowledge due to incomplete data or an incomplete understanding of a process (U.S. EPA, 2010). It is often the case that there are insufficient data to characterize all of the aspects of a population, to fully parameterize the exposure scenario, or to precisely model the exposure scenario. Each of these instances of lack of data introduces uncertainty to the exposure assessment. In order to be protective of the most exposed or most vulnerable individuals in a population, exposure assessors use conservative assumptions when the data available are insufficient (U.S. EPA, 1992).

Variability and uncertainty in exposure assessment will be discussed in greater detail in EXAs 406 and 407.

3. USING EXPOSURE SCENARIOS

Exposure scenarios are constructed to provide a framework to characterize and quantify exposure and dose. After exposure scenarios have been constructed, required data for each of the scenario characteristics would be collected. The specific scenarios evaluated for a risk assessment would depend on current conditions at the site as well as possible future conditions at the site. Data collection and parameterization of an exposure scenario will be discussed in more detail in subsequent EXA courses.

EPA's ORD, other program offices of EPA, and a number of organizations have developed guidance documents that advise risk assessors on how to conduct an exposure assessment within the context of that organization's assessment or regulatory context. A few such documents include:

- NCEA's Example Exposure Scenarios document (U.S. EPA, 2004a), developed in part to illustrate how data included in EPA's Exposure Factors Handbook (2011, 1997) can be used to parameterize exposure scenarios;
- The Risk Assessment Guidance for Superfund (RAGS) developed by EPA's Office of Solid Waste and Emergency Response, which provides instructions on conducting a risk assessment at a Superfund waste site (U.S. EPA, 2004b, 2001a, b, 1999, 1991a, b); and
- The Air Toxics Risk Assessment (ATRA) Reference Library developed by OAQPS, which provides a general overview and some specific guidelines on conducting exposure assessments for air pollutants; and

Other EPA offices have their own guidance documents and operational procedures that they use when conducting exposure assessments. For example, the Office of Water evaluates a limited number of exposure scenarios in developing Ambient Water Quality Criteria (AWQC).

The example and guideline scenarios in the documents above represent commonly encountered exposure pathways that could be of potential concern. Scenarios like these were developed as templates upon which site-specific assessments could be built. In general, the scenarios involve exposures via the ingestion, inhalation, and dermal routes, but each scenario must be tailored to the exposure assessment for which it is being used.

In conclusion, exposure scenarios are a tool for risk assessment that provide a framework for quantifying exposure. An exposure scenario includes information on the exposure setting, the chemicals of concern, source(s) of contamination, exposure pathways and exposure routes, environmental and exposure media, intake and uptake rates, and the receptors of concern.

EPA has developed various example exposure scenarios that can be helpful in evaluating ingestion, inhalation, and dermal exposures. The example exposure scenarios represent commonly encountered exposure pathways. Assessors should use the representative examples to formulate scenarios that are appropriate to the assessment of interest (U.S. EPA, 2004a).

4. REFERENCES

U.S. EPA (U.S. Environmental Protection Agency). (1989). Risk assessment guidance for superfund: Volume 1: Human health evaluation manual (part A): Interim final. (EPA/540/1-89/002). Washington, DC: U.S. Environmental Protection Agency, Office of Emergency and Remedial Response.

U.S. EPA (U.S. Environmental Protection Agency). (1991a). Risk Assessment Guidance for Superfund (RAGS): Volume I - human health evaluation manual (part B, development of risk-based preliminary remediation goals): Interim. Washington, DC. http://www.epa.gov/oswer/riskassessment/ragsb/index.htm.

U.S. EPA (U.S. Environmental Protection Agency). (1991b). Risk assessment guidance for superfund: Volume I - human health evaluation manual (part C, risk evaluation and remedial alternatives): Interim, appendix C: Short-term toxicity values. (OSWER Dir 9285.7-01CFS). Washington, D.C. http://www.epa.gov/oswer/riskassessment/ragsc/index.htm.

U.S. EPA (U.S. Environmental Protection Agency). (1992). Guidelines for exposure assessment. (EPA/600/Z-92/001). Washington, DC: U.S. Environmental Protection Agency, Risk Assessment Forum. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=15263.

U.S. EPA (U.S. Environmental Protection Agency). (1997). Exposure factors handbook (final report). (EPA/600/P-95/002Fa-c). Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=12464.

U.S. EPA (U.S. Environmental Protection Agency). (1998). Methodology for assessing health risks associated with multiple pathways of exposure to combustor emissions. (EPA 600/R-98/137). Washington, DC. http://cfpub.epa.gov/ncea/CFM/recordisplay.cfm?deid=55525.

U.S. EPA (U.S. Environmental Protection Agency). (1999). Risk Assessment Guidance for Superfund (RAGS): Volume I - human health evaluation manual, supplement to part A: Community involvement in Superfund risk assessments. (EPA/540-R-98-042). Washington, DC. http://www.epa.gov/oswer/riskassessment/ragsa/pdf/ci_ra.pdf.

U.S. EPA (U.S. Environmental Protection Agency). (2001a). Risk Assessment Guidance for Superfund (RAGS), Vol. I - Human health evaluation manual, Part D: Standardized planning, reporting and review of Superfund risk assessments. (OSWER9285747). Washington, DC. http://www.epa.gov/oswer/riskassessment/ragsd/index.htm.

U.S. EPA (U.S. Environmental Protection Agency). (2001b). Risk assessment guidance for superfund: Volume III - part A, process for conducting probabilistic risk assessment. (EPA 540-R-02-002). Washington, DC: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. http://www.epa.gov/oswer/riskassessment/rags3adt/index.htm.

U.S. EPA (U.S. Environmental Protection Agency). (2004a). Example exposure scenarios. (EPA 600/R03/036). Washington, DC. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=85843.

U.S. EPA (U.S. Environmental Protection Agency). (2004b). Risk Assessment Guidance for Superfund (RAGS), Volume I: Human health evaluation manual, (part E: Supplemental guidance for dermal risk assessment): Final. (EPA/540/R/99/005). Washington, DC. http://www.epa.gov/oswer/riskassessment/ragse/index.htm.

U.S. EPA (U.S. Environmental Protection Agency). (2008). Child-specific exposure factors handbook. (EPA/600/R-06/096F). Washington, DC: U.S. Environmental Protection Agency, National Center for Environmental Assessment. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=199243.

U.S. EPA (U.S. Environmental Protection Agency). (2010). IRIS site help and tools: Glossary, acronyms and abbreviations. Available online at http://www.epa.gov/ncea/iris/help_gloss.htm (accessed August 23, 2010).

U.S. EPA (U.S. Environmental Protection Agency). (2011). Exposure factors handbook 2011 edition (final). (EPA/600/R-09/052F). http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=236252.

Williams, P; Hubbell, BJ; Weber, E; Fehrenbacher, C; Hrdy, D; Zartarian, V. (2010). An overview of exposure assessment models used by the U.S. Environmental Protection Agency. In G Hanrahan (Ed.), Modelling of pollutants in complex environmental systems (pp. 61-131). Hertfordshire, UK: ILM Publications.