

## **Slide 1: Alternatives Analysis Workshop on Life Cycle Impacts & Exposure Assessment**

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## **Slide 2: Overview of Exposure Assessment Concepts and Tools**

Dr. Arturo Keller (Aug 9th, 1:00pm to 2:40pm)

### **Slide 3: Outline**

- Overview of human and ecological health RA in relationship to AA
- Toxicity assessment
- Exposure assessment
  - Source release estimates
  - Fate and transport estimates
  - Exposure routes (ingestion, inhalation, dermal)
  - Outdoor exposure
  - Indoor exposure
- Risk characterization
- Uncertainty considerations
- Key Points

### **Slide 4: AA Simple Diagram**

Figure showing how the Chemical of Concern and the Priority Product Categories are narrowed down to a Chemical of Concern in a specific product (the Priority Product). Manufacturers of the Priority Product conducted either a two-stage Alternatives Analysis or an Abridged AA. The two-staged AA process consists of a first-stage AA which is qualitative and a second-stage AA which is quantitative.

**Slide 5: Risk Assessment Knowledge that Can Be Used During Step 3 of the First Stage AA**

Figure showing the six steps associated with the first-stage AA. Step 1 is the Identification of product requirements and chemical function. Step 2 is the Identification of alternatives. Step 3 is the Identification of relevant factors. Step 4 is the Initial Evaluation and screening of alternatives replacement chemicals. Step 5 is the Consideration of additional information. Step 6 is the Preliminary Alternatives Analysis report. The figure highlights Step 3 where the user can apply their knowledge of exposure pathways from risk assessment to identify relevant factors.

**Slide 6: Risk Assessment Knowledge that Can Be Used During Step 4 of the First Stage AA**

The figure highlights Step 4 in the first-stage AA. The user can apply their knowledge of toxicity and environmental fate from risk assessment during the initial evaluation and screening of alternative replacement chemicals.

**Slide 7: Risk Assessment Knowledge that Can Be Used During Steps 1 and 2 of the Second Stage AA**

Figure shows the five steps for a second-stage AA where an in-depth analysis is conducted. The five steps are: Step 1, identification of relevant factors; Step 2, comparison of the Priority Product and alternatives; Step 3, consideration of additional information; Step 4, alternatives selection decision, and Step 5, Final AA report. The figure highlights Steps 1 and 2 where the user can apply their knowledge of toxicity assessment, exposure assessment, and risk characterization used in risk assessment to identify relevant factors, and compare the Priority Product and alternatives.

## Slide 8: What is Risk Assessment?

- Focus here on Toxicity of a Chemical
  - Human and Ecological Health Risk
- Risk depends on:
  - Hazard = inherent toxicity of a chemical
  - Exposure
- Risk = Hazard \* Exposure
- Risk Characterization: combine the exposure information with the hazard information to determine the likelihood that an emission could cause harm to nearby individuals and population.

Risk is commonly defined as the combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence.

Hazard is defined as the potential to cause harm.

Source: <https://www.epa.gov/risk/about-risk-assessment#whatrisk>

Reference: <https://www.nap.edu/read/2125/chapter/7/>

## Slide 9: Basic Steps in Risk Assessment

Picture showing the four basic steps of risk assessment: hazard identification, exposure assessment, dose-response assessment, and risk characterization. Hazard identification involves looking at a product such as a paint stripper and determining the hazardous chemicals it contains. Exposure assessment involves identifying potential routes of exposure when using the product such as applying paint stripper to a surface. Dose-response assessment evaluates the possible short- or long-term negative outcomes due to exposure from the product such as lung cancer, nausea, or coma. Risk characterization ranks the likelihood a negative outcome may occur based on information from the previous steps.

**Slide 10: Basic Steps in Risk Assessment**

At a work site, hazard identification can be used to assess potential worker exposure to hazardous chemicals. Exposure assessment is used to assess the potential routes of exposure such as inhalation, ingestion or dermal contact. Dose-response assessment is used to determine a dose where no observed effect occurs and a dose range where an effect is observed. Risk characterization uses the information from the previous steps to rank the overall potential chemical exposure for all exposure pathways and settings to each chemical of concern.

**Slide 11: Risk Assessment Components can be used for Alternative Analysis**

- “...the SCP regulations do not require a traditional risk assessment that quantifies hazards and exposures to estimate risk. Instead, the AA uses potential exposure to identify relevant factors and compare alternatives.”
- “The regulations do not require a traditional risk assessment, but the responsible entity can use that approach if preferred.”

Reference: From the DTSC AA Guide pages 63 and 100.

**Slide 12: Risk Assessment versus Alternatives Analysis – Differences**

Topic	RA	AA
Objective	Risk characterization and risk management (e.g., minimize exposure)	Comparison of chemical alternatives to reduce hazard and minimize exposure
Aspects to consider	What is the exposure level?  What is the risk associated with the exposure?	Is this potentially hazardous activity/product necessary?  How can the hazard be reduced or eliminated?  What other options are available?
Activities relationship	Activities typically considered in isolation	Multiple activities compared

### **Slide 13: Toxicity Assessment**

Figure showing toxicity assessment consists of: (1) hazard identification where you ask “Are there adverse effects?” is asked, and (2) dose-response assessment where you ask “At what dose does the adverse effect occur?”

### **Slide 14: Types of Human Health Hazards**

Human health hazards consists of two types: carcinogenic and non-carcinogenic. Carcinogenic human health hazards are organ specific; typically require chronic exposure; cause a carcinogen to bind to DNA; cause DNA damage; and cause gene alteration. Non-carcinogenic human health hazards are acute or chronic toxicity; cause irritation; are a skin sensitizer; cause reproduction effects; cause developmental effects; cause liver or kidney damage; cause anesthesia; and cause breathing difficulty/asthma.

Carcinogenic vs. Non-carcinogenic

NOTE: Carcinogens may also provoke other toxic effects (i.e. may also have non-carcinogenic risk)

Non-carcinogenic health effects:

Acute toxicity, Irritation, Skin sensitizer, Reproduction effects, Developmental effects, Immune system effects, Neurotoxicity, Genotoxicity, Mutagenicity, Etc.

### **Slide 15: Dose-Response Assessment**

- Objective: quantitative evaluation of toxicity and characterization of the dose-response relationship
- Threshold vs. Non-threshold

Some pollutants require an exposure above a threshold level or dose during a continuous exposure episode to cause toxic effects.

Figure of a dose-response curve with a no-effect region. The curve is an x-y plot where increasing dose is on the x-axis and increasing effect is on the y-axis. The area between 0 and a threshold dose on the x-axis is the no-effect range. The range of increasing effect with increasing dose is an asymptotic curve that lies between the threshold dose and the maximum dose. The increasing effect plateaus after the maximum dose which is the maximum effect range.

### Slide 16: Dose-Response Graph

Dose-response graph with dose in milligrams per kilogram-body-weight-day along the x-axis, and response in percent along the y-axis. The response is the percentage of animals that died from exposure to the chemical. Three data points are shown:

- (1) The no-observable-adverse-effect-level or NOAEL,
- (2) The lowest-observable-adverse-effect-level or LOAEL, and
- (3) The lethal dose at 50% or LD 50.

For this graph the NOAEL = 8 milligrams per kilogram-body-weight-day with a response = 0%, the LOAEL = 15 milligrams per kilogram-body-weight-day with a response = 20%, and the LD50 = 18 milligrams per kilogram-body-weight-day with a response = 50%.

### Slide 17: Non-Carcinogenic – Reference Dose

- Reference Dose (RfD)
  - daily dose considered safe for population over lifetime
  - mg/kg-bw-day

$$RfD = \frac{NOAEL \text{ or } LOAEL}{UF \times MF}$$

- UF = Uncertainty factor
- MF = Modifying factor

Provides estimate of continuous daily exposure for the general population (including sensitive groups) without an appreciable deleterious effect

If the LOAEL is used instead of the NOAEL, then the Uncertainty Factor is corrected by another factor of 10, to correct for the extrapolation from LOAEL to NOAEL.

### Slide 18: Uncertainty Factor and Modifying Factor

- Uncertainty Factor (UF)
  - The factor of 10 is the default value.
  - Use a factor of 10 for extrapolating from
    - Valid experiments to prolonged exposure of healthy humans, accounting for sensitivity. (10H)
    - Valid studies on animals (in the absence of valid human studies). (10A)
    - Than chronic results on animals (sub-chronic). (10 S)
- Use an additional factor of 10 when the results from animal studies are “incomplete” or “inconclusive” but warrant taking precautions. (10L)
- Modifying Factor (MF)
  - Additional uncertainty factor, determined by “professional judgment” when the uncertainties in the study warrant it. Varies from 0.1 to 10. Default value is 1.

### Slide 19: Toxicity Assessment: Non-carcinogens

- Sample calculation of RfD:
  - A study is made with 250 rats that determines that there is “No Observable Adverse Effect” (NOAEL) at 5 mg/kg-day

Example calculation of the reference dose where the No-Observed-Adverse-Effects-Limit equals 5 milligrams per kilogram-day, the uncertainty factor equals the product of 10H times 10A times 10 S = 1000, and the modifying factor equals 0.75 for a large number of animals. The reference dose equals 5 milligrams per kilogram-body-weight-day divided by the product of 1000 times 0.75 which equals 0.007 milligrams per kilograms-day.

### Slide 20: Dose-Response Curve for Carcinogens

Dose-response curve relationship for carcinogens. The graph is an x-y plot with dose of the test chemical in milligrams per kilograms-day along the x-axis and excess tumor incidence in percent along the y-axis. A best-fit line with a rise of approximately 10% and run of approximately 0.1 mg/kg-day is drawn through the data points and extrapolated back to the origin where x=0 and y=0.

### Slide 21: Toxicity Assessment: Carcinogens

- Assume there is no threshold level for carcinogenic effects
- Estimate “excess” cancer per unit dose
  - SF - slope factor
    - in units of risk per mg/kg day
- Very conservative assumptions
- Determined as the increased lifetime risk per unit of dose

Dose response curve with the dose in log scale along the x-axis and percent risk of cancer along the y-axis. The zero threshold dose is shown at the origin where the x- and y-values are zero. An asymptotic curve is shown representing the dose-response curve which is based on actual test results. A line is extrapolated through the zero threshold dose to the upper confidence level of the lowest dose that caused cancer.

### Slide 22: Cancer Risk Calculation

- Calculation of risk-specific concentrations in air:

$$C_a^* = \frac{mg}{m^3} = \frac{\text{specified risk level} \times \text{body weight}}{SF_i \times \text{inhalation rate}}$$

Mathematical equation for cancer risk: the concentration in air is equal to the product of the specified risk level times the body weight divided by the product of the inhalation cancer slope factor times the inhalation rate. For this example, the specified risk level equals 0.000001, the body weight equals 70 kg, and the inhalation rate equals 20 cubic meters per day. The concentration in air in milligrams per cubic meter equals the product of 0.000001 times 70 kg divided by the product of 20 cubic meters per day times the inhalation cancer slope factor which equals 0.0035 divided by the inhalation cancer slope factor.

### Slide 23: Types of Ecological Hazards

Figure shows the ecological hazards consist of acute toxicity and chronic toxicity. Acute toxicity is the adverse effects of a substance in a short period of time where the effect could be lethal or sub-lethal. Chronic toxicity is the cumulative damage to specific organ systems over a longer time period.

## Slide 24: Types of Ecological Hazards

Figure showing the types of ecological hazards associated with acute toxicity and chronic toxicity. Acute toxicity hazards are lethal concentration at 50% for fish (Fish LC50), lethal concentration at 50% for daphnid (Daphnid LC50), and median effective concentration at 50% on green algae growth (Green algae EC50). Chronic toxicity hazards are chronic toxicity value for fish (Fish ChV), chronic toxicity value for daphnid (Daphnid ChV), and chronic toxicity value for green algae (Green Algae ChV).

## Slide 25: Species Sensitivity Distribution - SSD

- Cumulative probability distributions of toxicity values for multiple species
- Can estimate potentially affected fraction (PAF) at a given concentration

X-Y plot with concentration in micrograms per liter along the x-axis and potentially affected fraction in percent along the y-axis. For this example plot, exposure to 9 micrograms per liter of this example chemical causes toxicity in 40% of the species exposed.

## Slide 26: Species Sensitivity Distribution

Species sensitivity distribution for cadmium. The graph has cadmium concentration in milligrams per liter along the x-axis and proportion affected in percent along the y-axis. Several species are plotted as data points along an asymptotic curve. This graph is available at <https://www.epa.gov/caddis-vol4/ssd-plots>.

## Slide 27: Toxicity Data Sources

- TOXNET (<https://toxnet.nlm.nih.gov/>)
- CPDB (<https://toxnet.nlm.nih.gov/cpdb/>)
- HSDB (<https://toxnet.nlm.nih.gov/newtoxnet/hsdb.htm>)
- IRIS (<https://www.epa.gov/iris>)
- ECOTOX (<https://cfpub.epa.gov/ecotox/index.html>)
- Published studies

## Slide 28: Dose Matters

Picture with a quote from Paracelsus “All things are poisons, for there is nothing without poisonous qualities. It is only the dose which makes a thing poison.”

## Slide 29: What is Exposure?

- Contact between chemical and human or ecological receptor for a specific time duration
- Exposure media
  - Air
  - Water
  - Soil
  - Food
- Exposure routes:
  - Inhalation
  - Ingestion
  - Dermal contact

Cartoon depicting contact, ingestion, and inhalation taken from <https://www.ableemployment.com/component/zoo/item/first-aid-for-chemical-exposure-are-you-prepared>.

Conceptual model titled “How are Plants and Animals Exposed to Contaminants?” taken from [http://savethehousatonic.org/?page\\_id=62](http://savethehousatonic.org/?page_id=62). This model shows how contaminants in sediments and water are absorbed by plants which are eaten by fish and other mammals. Fish and mammals may also be exposed to the chemical in the water that is ingested or by direct contact.

Some useful definitions are listed below:

- Exposure:** The contact between a chemical and a human or ecological receptor for a specific duration of time. Exposure occurs by contact with a chemical through various exposure media (air, water, soil, and food) via exposure routes (inhalation, ingestion, and dermal contact).
- Exposure Assessment:** Exposure assessment is the process of estimating or measuring the magnitude, frequency and duration of exposure to an agent, along with the number and characteristics of the population exposed. Ideally, it describes the sources, pathways, routes, and the uncertainties in the assessment.
- Exposure Factor:** As used in this Guide, this term is associated with potential relevant factors used to compare a Priority Product with alternatives. It may include market presence of the product; the occurrence, or potential occurrence, of exposures to the Candidate Chemical(s) in the product; the household and workplace presence of the product and other products containing the same Candidate Chemical(s) that formed the

basis for prioritization of the product-chemical combination as a Priority Product; and potential exposures to the Candidate Chemical(s) in the product during the product's life cycle.

- Exposure Pathway:** The route a stressor takes from its source to its human or ecological receptor. An exposure pathway is associated with potential relevant factors used to compare the Priority Product with the alternatives.

### **Slide 30: Major Components in Exposure Assessment**

Diagram showing four major components in exposure assessment: use, release, fate & transport, and exposure. Quantity is a factor to consider during use, release, and fate & transport.

### **Slide 31: Life-Cycle Releases**

Schematic showing life-cycle releases for the production, use and disposal life-cycle phases. During the "Production" phase, the chemical may be emitted directly to the air, to water via the wastewater treatment plant, and to landfills. During the "Use" phase, the chemical in the product could be released directly to the air, water, and soil. After the "Use" phase, the chemical in the product may be released to wastewater treatment plants which discharge to water, and disposed of as waste and sent to landfills. Wastewater treatment plants may send waste to landfills and soils. Some waste from wastewater treatment plants and disposal may be sent to waste incineration plants which may release the chemical to the air and landfills.

### **Slide 32: Estimating Release**

- Manufacturing
- Product use
  - Direct to consumer
  - To surroundings
- Disposal methods
  - Wastewater
  - Incineration
  - Landfill

Photos of a worker in a welding area, a worker sanding a wooden deck, and someone pouring a pink chemical in a sink.

### **Slide 33: Chemical Product – Industrial Use**

Photos of a worker using a hand sander, workers in yellow Tyvek spraying a field, workers using a high-power pressure washer, and a worker spray painting an automobile.

### **Slide 34: Chemical Product – Consumer Use**

Photos of someone applying lotion to their hand, someone painting a room, someone using a pesticide on their plants, and a worker spraying pesticide along a house's foundation.

### **Slide 35: Important Physicochemical Parameters**

- Important Physicochemical Parameters for chemical Release
  - Volatility
  - Water solubility
  - Octanol/Water partitioning (Kow, Kp)
    - Predicts bioaccumulation

### **Slide 36: Releases Estimation Approach**

- Bottom-up Approach
  - Based on specific consumer product type and use patterns
  - Need to know use or application rates
  - Need to calculate release to different compartments in different life-cycle stages
- Top-down Approach
  - Based on
    - functional uses
    - product categories
    - generic release factors

### **Slide 37: Bottom-up Approach**

- Based on product use information
- Volatilization – based on vapor pressure
- Dissolution in water – based on solubility
- Likelihood of spill
- Non-intended uses or releases?

Picture of a paint stripper used on a wall that may evaporate to the air or be released to a drain during use.

### **Slide 38: Examples**

Figure showing two examples on how to estimate releases: one for methylene chloride in a paint stripper, and the other for shampoo.

A paint stripper containing methylene chloride is used on a 100 meter square section of wall. Assuming 0.8325 kilograms per meter square of methylene chloride is in the product, approximately 83 kg of methylene chloride is released to the air and 0.25 kilograms of methylene chloride is released to the wastewater treatment plant.

Using shampoo, we assume 10 milliliter of shampoo is used per showering event which is equivalent to 0.1 grams per milliliter. The amount of shampoo used per showering event is equal to 1 gram or 0.001 kilograms of shampoo used per showering event. If 6 million people shower once per day, approximately 6,000 kilograms of shampoo is released to the wastewater treatment plant.

### **Slide 39: Top-down Release Estimation**

Conceptual diagram for estimating releases using a top-down method. The functional uses of the chemicals are classified as solvents, surfactants, flame retardants, pesticides, etc. and may be determined using a functional uses classifier. Based on the functional use, market share data may be used to determine the product categories such as personal care products, crop protection products, paint & coatings, electronics, etc. Based on the product categories, release factors can be determined such as air, wastewater, soil, and landfill.

Reference: Tao, M., Li, D., Song, R., Suh, S., & Keller, A. A. (2018). OrganoRelease—A framework for modeling the release of organic chemicals from the use and post-use of consumer products. *Environmental Pollution*, 234, 751-761

#### **Slide 40: Chemical Functional-Use Classes**

- Antimicrobials
- Chelating Agents
- Colorants
- Defoamers
- Emollients
- Enzymes and Enzyme Stabilizers
- Fragrances
- Oxidants and Oxidant stabilizers
- Polymers
- Preservatives and Antioxidants
- Processing aids and Additives
- Skin conditioning agents
- Solvents
- Specialized industrial chemicals
- Surfactants

Reference: <https://www.epa.gov/saferchoice/safer-ingredients#searchList>

#### **Slide 41: Solvents in Consumer Products**

Screenshot of Table 17-4, Frequency of Use for Household Solvent Products (users only) from the 2011 US EPA Exposure Factors Handbook. Table 17-4 lists the mean in use per year, the standard deviation, and the percentile rankings for frequency of use per year for several general product descriptions.

#### **Slide 42: Solvents in Consumer Products**

Screenshot of Table 17-6, Amount of Products Used for Household Solvent Products (users only) from the 2011 US EPA Exposure Factors Handbook. Table 17-6 lists the mean in ounces per year, the standard deviation, and the percentile rankings for the amount of products used in ounces per year for several general product descriptions.

### Slide 43: Sources of Release Factors

- European Union Technical Guidance Documents (EU TGD)
- European Union specific environmental release categories (SPERCs)
- CHESAR (CHEmical Safety Assessment and Reporting Tool)
- ECETOC TRA (European Center for Ecotoxicology and Toxicology of Chemicals Targeted Risk Assessment)
- Easy TRA (EASY Targeted Risk Assessment)
- CLiCC OrganoRelease

### Slide 44: Example: Release Estimate

Chemical structure of TBAC – tertiary-butyl acetate

- Generally used as a solvent in paints
- Also used as a solvent in other applications
- Solubility of 8.3 g/L in water
- Vapor pressure of 47 mm Hg at 25 C

### Slide 45: Release Estimate

Figure showing the mass flow (in percent) of tertiary-butyl acetate (TBAC) based on solvent market share data, using the midpoint of the range of values. The estimated mass flow of TBAC used as a solvent equals 100.00%. The different processes that use TBAC as a solvent are broken down as follows: adhesives & sealants equals 2.76%; paints & coatings equals 60.90%; printing inks equals 9.60%; other uses equals 16.47%; personal care products equals 2.76%; and pharmaceuticals equals 7.51%. The release factors for each product category are selected from SPERC and EU TGD which are: indoor air releases equal 87.91% for adhesives & sealants, paints & coatings, printing inks, and other uses; soil releases equal 0.71% for other uses, and paints & coatings; wastewater releases equal 5.77% for paints & coatings, printing inks, other uses, TBAC, and pharmaceuticals; and waste releases equal 5.61% for pharmaceuticals.

Reference: Tao, M., Li, D., Song, R., Suh, S., & Keller, A. A. (2018). OrganoRelease—A framework for modeling the release of organic chemicals from the use and post-use of consumer products. *Environmental Pollution*, 234, 751-761.

#### **Slide 46: Scaling Release**

Figure showing information used to scale releases for methylene chloride and benzyl alcohol. Bar graph showing the total use of benzyl alcohol of 110 million kilograms per year and methylene chloride of 90 million kilograms per year. 25% of the products used in the US are paint strippers. 50% of the users of paint strippers are consumers. Total California population as 325 million people where 6.1 million people are located in the San Francisco Bay area. Regional use of the methylene chloride and benzyl alcohol is 0.20 million kilograms per year and 0.28 million kilograms per year, respectively. When the chemical is used, 20% is used indoor and 80% is used outdoors.

#### **Slide 47: Different Release Scenarios**

X-Y graph plot showing six types of release scenarios where time is along the x-axis and release in kilograms per day is along the y-axis. A seasonal or cyclical use may appear as a sine wave. Continuous use will be a horizontal line set at one release value. Sporadic use may consist of peaks, square waves, etc. with no given pattern either based on time or release. An accidental spill may appear as a single peak on a flat line. Phase-out may appear as a line where the release value decreases over time. Increasing use is a line where the release value increases over time.

#### **Slide 48: Life-Cycle Releases**

Schematic showing life-cycle releases for the production, use and disposal life-cycle phases. During the "Production" phase, the chemical may be emitted directly to the air, to water via the wastewater treatment plant, and to landfills. During the "Use" phase, the chemical in the product could be released directly to the air, water, and soil. After the "Use" phase, the chemical in the product may be released to wastewater treatment plants which discharge to water, and disposed of as waste and sent to landfills. Wastewater treatment plants may send waste to landfills and soils. Some waste from wastewater treatment plants and disposal may be sent to waste incineration plants which may release the chemical to the air and landfills.

#### **Slide 49: Wastewater Treatment Processes**

Conceptual model showing the primary, secondary, and tertiary treatment phases in a wastewater treatment process. Wastewater undergoes primary treatment in three steps where it is: (1) filtered using a coarse debris screen, (2) sent through a cyclone to remove sand and grit, and (3) sent to the primary clarification unit to remove fine solids. The fine solids create a sludge that is sent to the sludge digesters. After the primary treatment, the wastewater goes through secondary treatment where the water is aerated, sent to a clarification unit to remove more fine solids, and then disinfected with chlorine or ultraviolet light. The fine solids removed in the clarification unit create a sludge that is sent to the sludge digesters. In tertiary treatment, nutrients in the water are removed before the water is released as effluent. Reference: <http://css.umich.edu/factsheets/us-wastewater-treatment-factsheet>

Outputs:

- Emissions to air
- Effluent to freshwater, marine
- Sludge to biosolids (agriculture?) and landfill

#### **Slide 50: Waste Incineration Processes**

Conceptual model showing the different units in a waste incineration process. Garbage enters the incinerator via an input device. The incinerator's exhaust is released to a waste heat boiler to capture the heat. The cooled exhaust is sent to a multi-cyclone to remove any large particulate matter. Next, the exhaust is sent to a dry electrostatic precipitator where finer particulate matter is removed and the clean air is drawn out of the electrostatic precipitator using a fan. The air pulled out by the fan is released to the outside via a stack. Reference: [http://www.hitachi-infra.com.sg/services/energy/dustcollection/case/industrial\\_incinerator.html](http://www.hitachi-infra.com.sg/services/energy/dustcollection/case/industrial_incinerator.html)

Outputs:

- Emission to air (gases and particulate matter, PM)
- Ashes to landfill or embedded in products

### **Slide 51: Landfill Process**

Simplified cross-section of a landfill showing from the bottom-up: the liner system, leachate collection system, the waste layer, the cover system, and the vegetative layer. Two gas collection wells are installed that go through the vegetative and cover layers to penetrate the waste layer. A monitoring well is installed near the landfill which extends down to the water table below the landfill. Reference: <http://greensciencepolicy.org/design-and-operation-of-landfills>

Outputs:

- Emissions to air?
- Emissions to groundwater?

### **Slide 52: Major Components in Exposure Assessment**

Diagram showing four major components in exposure assessment: use, release, fate & transport, and exposure. Fate is a factor to consider during fate & transport.

### **Slide 53: Transport & Fate**

- Objective
  - Predict concentrations at receptors
    - Human
    - Ecological
  - For all relevant pathways
    - Air (indoor & outdoor)
    - Water (drinking, swimming, habitat)
    - Soils (cropland, recreational, habitat)
  - Determine residence times in different environmental compartments
    - Persistence

#### **Slide 54: Multimedia Fate and Transport Model**

Conceptual model showing how a chemical is released and travels through the environment. Particulates and vapors, aka contaminants, are emitted from a manufacturing source to the air where they are dispersed. Some contaminants may be deposited on the land from the air or fall as rain. Trees and other plants may take up the contaminants through their leaves from the atmosphere. The contaminants may also be deposited onto water bodies where they settle out into sediment or are adsorbed by the water. Plants, fish, and animals that drink the contaminated water or eat contaminated plants transfer the contaminants to the food chain. Predators that eat fish and other animals may ingest the contaminants in their prey. Conceptual model from <https://www.epa.gov/fera/multimedia-fate-transport-modeling-overview>.

#### **Slide 55: Consumer Product Fate**

Conceptual model showing the fate of a consumer product. Pesticides are applied to and absorbed by crop plants. The pesticides may vaporize into the atmosphere and be degraded by ultraviolet light. The pesticides and their degradation products are deposited on water bodies and land via rainfall. Surface water runoff may also contribute to pesticides in lakes and rivers. The pesticides that adhere to the soil may be degraded by bacterial oxidation or chemical hydrolysis, or be leached below the root zone by rain or irrigation. Some of the leached water containing pesticides may be released to nearby water bodies. The conceptual model is from <https://www.slideshare.net/vibhurathore9/environmental-alteration-of-pesticides>.

#### **Slide 56: Indoor Air Fate**

Conceptual model of a home's indoor air. Indoor air has many pollutants sources such as furniture, paint, flooring, cleaning products, etc. Air pollutants may also come into the home from outside air and contain a mix of primary and secondary air pollutants such as carbon monoxide, carbon dioxide, nitrous oxides, sulfur oxides, particulate matter, and volatile organic compounds. Pollutants from indoor air sources may react with each other or outside air pollutants to create byproducts. The indoor air pollutants and their byproducts may be lost to surfaces due to deposition, adsorption, chemical reactions, and removal by ventilation and portable filters or resuspended by off-gassing from surfaces. Conceptual model from <http://jtd.amesgroup.com/article/view/3709/html>.

### Slide 57: Transport Processes

- Advection (convection)
  - Carried along with currents
- Diffusion & Dispersion
  - Spread out via mechanical mixing or molecular interactions
- Sorption & Retardation
  - Slowing down due to attachment to a solid surface
- Sedimentation & Resuspension of particles
  - Contaminants may be adsorbed to particles

### Slide 58: Fate Processes

- Biodegradation
  - Mostly microbes and fungi doing the work
  - Aerobic (requires oxygen)
  - Anaerobic (e.g. deep soils, river and lake sediments)
- Chemical Transformations
  - Atmospheric oxidation
  - Photolysis (directly by light source)
  - Hydrolysis (only in water)
  - Aqueous oxidation or reduction
- Bioaccumulation
  - Transfer up the food chain

### Slide 59: Biomagnification

Two conceptual models on biomagnification.

The left figure shows how a contaminant is concentrated as it moves up the food chain. The chemical concentration starts off at 0.000003 ppm in water and increases to 0.04 ppm in zooplankton. Small fish feed on the zooplankton and concentrate the chemical to 0.5 ppm. A large fish feeds on the small fish concentrating the chemical to 2 ppm. The chemical concentrates to 25 ppm in fish-eating birds of prey that feed on large fish.

The right figure shows how the mercury concentration increases from water to algae to algae eating insects to insect eating insects to insect eating fish to fish eating fish to humans.

## Slide 60: Different Types of Fate & Transport Models

- Media specific models
  - Air
  - River
  - Groundwater
- Multi-media models
  - Box models

## Slide 61: Air Quality Model Example

The CATT-BRAMS 3D Eulerian model grid box was designed to simulate and study emission, deposition, and transport of gases and aerosols associated with biomass burning in South America. The model grid box has a length and width along the x- and y- axes between 10 and 100 kilometers. The height of the box is between 1000 meters and 20 and 30 kilometers along the z-axis. The model determines how pollutants from a fire are transported by considering the plume rise of the smoke, and convective transport by shallow cumulus clouds and deep cumulus clouds. Diffusion in the planetary boundary layer (between the air and land) and dry deposition from the air are also considered. Wet deposition in the form rain is also modeled. The model grid box is from <http://aqicn.org/faq/>.

## Slide 62: Air Quality Model Example

Figure describes the general structure of air pollution models. The air quality model output is a concentration distribution based on four types of input: emissions, meteorology, atmospheric chemistry, and surface properties.

## Slide 63: Air Quality Model Example

Figure shows three examples of air quality heat maps or topographical maps. These heat maps use colors assigned to specific concentration ranges to communicate the chemical's extent and intensity and transport direction over a given area.

## Slide 64: Indoor Air Model

Figure on modelling indoor air quality.

The left-side of the figure is on modelling indoor air quality using a material balance "box model". A mathematical equation is shown for calculating the accumulation rate.

$$V \frac{dC}{dt} = S + C_a IV - CIV - KCV$$

The accumulation rate (V multiplied by the differential of C over the differential t) is equal to the input rate (S) plus the sources (product of C subscript "a" times I times V) minus the output rate (product of C times I times V) minus the decay (product of K times C times V).

- C = indoor concentration in milligrams per cubic meter.
- V = volume of conditioned space in the building in cubic meters per air change.
- I = the flow (Q) divided by V = infiltration rate as air change.
- S = pollutant source strength in milligrams per hour.
- $C_a$  = ambient or outside concentration of the pollutant in milligrams per cubic meter.
- K = decay rate or reaction rate of the pollutant in 1 per hour.

Reference: <https://www.chegg.com/>

The right-side of the figure is a heat map of the interior of a conceptual vehicle where color is used to show the distribution of carbon monoxide concentration in the cabin.

## Slide 65: Indoor Air Model

Mathematical equation for calculating the concentration in an enclosed system using box model equation.

$$C(t) = \left[ \frac{S}{V} + nC_{in} \right] (1 - \exp^{-(n+k)t}) + C_o \exp^{-(n+k)t}$$

Where S = source emission rate inside the enclosure (mass per time)

V = volume of the enclosure

$C_{in}$  = concentration of analyte coming into the enclosure with the air flow (mass per volume)

k = decay constant ( $time^{-1}$ ) that accounts for chemical or physical loss of the compound in the system (room, building, lake)

$C_o$  = initial concentration in the room (mass per volume)

n = air exchange rate of enclosure ( $time^{-1}$ ) = enclosure volumes exchanged per hour

For mechanical ventilation,

n = air flow rate through the room divided by room volume ( $time^{-1}$ )

Reference: <https://www.chegg.com/>

## Slide 66: Multi-media Models

- SimpleBox (RIVM)
  - RIVM – Dutch National Institute for Public Health and the Environment, Ministry of Health, Welfare and Sport
  - used in USETox, EUSES, CHESAR
  - [https://www.rivm.nl/en/Topics/S/Soil\\_and\\_water/SimpleBox](https://www.rivm.nl/en/Topics/S/Soil_and_water/SimpleBox)
- EQC (Equilibrium Criteria Model – Level I, II, III)
  - <http://www.trentu.ca/academic/aminss/envmodel/models/NewEQCv100.html>
- BETR Global (UC Berkeley)
  - <https://sites.google.com/site/betrglobal/home>
- CLiCC (Chemical Life Cycle Collaborative)
  - <https://clicc.net/>

### **Slide 67: Model Framework**

Figure shows how emissions may be deposited on natural soil or on soil in urban areas, and agricultural areas where biosolids may or may not be used. Only emissions deposited on urban soil has the potential to be transferred to the deep soil by pore water. Natural soil may transfer emission to freshwater. Air emissions may be deposited on freshwater and coastal waters or deposited over coastal waters via aerosols. Emission in freshwater may be suspended in the water column or deposited in and re-suspended from the sediment. In coastal waters, emissions may be suspended in the water or deposited in and re-suspended from the sediment.

### **Slide 68: Mathematical Model**

Concentration = Release + Transfers in – Transfers out

Figure depicts a mathematical model for the equation concentration equals release plus transfers in minus transfer out. A simple conceptual model shows inputs into the water as wet/dry deposition, release, runoff, erosion, and resuspension. Outputs from the water are advection, degradation, and sedimentation. Diffusion and sorption may occur in suspended sediment in the water. Diffusion may also occur between the sediment and the water, and between the air and the water.

### **Slide 69: Conceptual Design**

Conceptual model showing an urban area, agricultural area, undeveloped area, and coastal marine area. Air may contain aerosols from the urban area. Wastewater from urban areas are treated at wastewater treatment plants which may release effluent to freshwater bodies such as rivers. Soils near urban areas or agricultural lands where biosolids are applied may be release water to freshwater and coastal waters. Soil is a combination of soil solids and soil water at the near surface and deep soil. Coastal marines consists of suspended sediment and sediment.

### **Slide 70: Fate and Transport Modeling**

Fate and transport modelling considers the transport mechanisms in the air, water, and soil. Mechanisms for the air over land include advection, attachment to aerosols, dry deposition, and wet deposition. Mechanisms in soil include infiltration, sorption, dissolution, and runoff to water bodies. In freshwater, mechanisms such as heteroaggregation, dissolution, and sedimentation are considered. Wind erosion and erosion to water bodies are considered for agricultural areas. For coastal marine areas, aerosol resuspension, suspended sediment, and advection are considered. Sediment mechanisms include resuspension into the water column, dissolution, and burial.

### **Slide 71: Regional Characteristics**

Two figures show different land use maps for the California Bay Area and an area northwest of Des Moines, Idaho. Five land uses are identified and assigned a color: light blue for freshwater, darker blue for marine, green for agriculture, purple for urban, and tan for undeveloped. The California Bay Area has urban areas immediately adjacent to the San Francisco Bay which are surrounded by undeveloped areas while most land northwest of Des Moines, Idaho is shown as agricultural areas.

### **Slide 72: Local Climatic Conditions**

Slide shows four graphs: (1) precipitation, (2) wind speed, (3) temperature, and (4) flow. The graphs show data collected over a 10 year period from 2005 to 2015. The pattern for Wind speed and temperature are cyclical patterns while precipitation and flow appears to show a decreasing trend.

### **Slide 73: Model Diagram**

Diagram showing four input types for a fate and transport model. The inputs are: (1) meteorological data such as precipitation and temperature, (2) environmental parameters such as soil type, land use, pH, and salinity, (3) chemical properties such as  $P_{sat}$ , octanol-water coefficient, and half-lives, and (4) chemical release such as kilograms per day. These inputs are processed in the model to determine chemical concentrations in the environment.

### **Slide 74: Sample Output**

Two graphs showing the results of methylene chloride and benzyl alcohol in freshwater, suspended sediment, sediment solids, and sediment water. The graphs have time in days along the x-axis and concentration in kilograms per cubic meter along the y-axis. Freshwater results are not shown on the graphs for either chemical. For sediment water, the results are a cyclic pattern oscillating between  $10E-6$  and  $10E-9$  for methylene chloride and  $10E-2$  and  $10E-4$  for benzyl alcohol over a 3000-day period. For suspended sediment, results are a cyclic pattern oscillating between  $10E-6$  and  $10E-8$  for methylene chloride and  $10E-2$  and  $10E-3$  for benzyl alcohol. For sediment solids, results are a cyclic pattern oscillating between  $10E-11$  and  $10E-13$  for methylene chloride and  $10E-7$  and  $10E-8$  for benzyl alcohol.

### **Slide 75: Major Components in Exposure Assessment**

Diagram showing four major components in exposure assessment: use, release, fate & transport, and exposure. The exposure phase is emphasized on the figure.

### **Slide 76: Potential Exposures during the Life Cycle**

Diagram shows the 11 life cycle stages: raw materials extraction, intermediate materials processes, manufacture, packaging, transportation, distribution, Use, operation & maintenance, waste generation & management, reuse & recycling, and end-of-life disposal. Three life cycle stages are emphasized: manufacture, use, and reuse & recycling. When considering potential exposures for each life cycle stage, both direct and indirect exposure pathways need to be considered. A question to ask during the manufacture life cycle stage is "Are there worker exposures to the chemical of concern?" Several questions to consider for the use phase are: "What are the exposure pathways?" "What is the exposure duration or intensity?" and "What are the exposure routes?" For the reuse & recycling life-cycle stage, a question to ask is "Is there a potential for exposure to the Chemical of Concern?"

## Slide 77: Exposure

Diagram of the mathematical equation for exposure where exposure is equal to the product of the concentration times the exposure factors integrated over time. When using this equation, one question to ask is “What is the exposure scenario?” Some questions to consider for the concentration term are: “What are the sources and releases?” “What is the media concentration?” and “How is the substance transported through the environment?” Questions to consider for the exposure factors are “Which population is exposed?” and “What are their characteristics and exposure factors?”

Reference: <https://www.epa.gov/expobox/exposure-assessment-tools-approaches-indirect-estimation-scenario-evaluation>

## Slide 78: Conceptual Model – Exposure

Constructing a conceptual model is useful in illustrating potential exposure pathways and life cycle segments.

Figure 6-2 on page 72 of the DTSC AA Guide. Figure 6-2 is an example of a conceptual model receptor network. Four areas are identified: Primary source, secondary source, transport mechanisms, and exposure medium. The primary source is identified as the consumer product. Secondary sources listed are affected soil and affected groundwater. Transport mechanisms are airborne particulate matter, volatilize to soil gas, wastewater treatment effluent/storm water runoff, and leaching migration to groundwater. The exposure medium listed are food, soil, indoor ambient air, soil vapor, surface water body, groundwater, and indoor dust.

The primary source is linked directly to the secondary sources, indoor ambient air, soil vapor, and indoor dust.

The secondary sources link the primary source directly to an exposure medium or by various transport mechanisms. Affected soil is linked: (1) directly to food and soil, (2) to indoor ambient air and soil vapor by transporting the Chemical of Concern via airborne particulate matter and volatilizing the Chemical of Concern to soil gas, (3) to a surface water body via wastewater treatment effluent/storm water runoff, and (4) to the groundwater via leaching migration. Affected groundwater is linked: (1) directly to groundwater, and (2) to indoor ambient air and soil vapor by volatilizing the Chemical of Concern to soil gas which is shown as a reversible process.

A direct link between a surface water body contaminated with the Chemical of Concern and food is also shown.

For each exposure medium, a table is shown listing the exposure route and receptor type. The receptor types are further segregated into human that are consumers or workers, and ecological receptors that are terrestrial or aquatic. For food and soil, the ingestion exposure route affects all receptors while the inhalation and dermal routes affect human receptors (consumer and worker) and terrestrial ecological receptors. The exposure route for indoor ambient air and soil vapor is inhalation which affects human receptors (consumer and worker) and terrestrial ecological receptors. For surface water bodies, ecological receptors (terrestrial and aquatic) may be affected by ingesting contaminated water while all receptors (human and ecological) may be affected by dermal contact to contaminated water. Human receptors (consumer and worker) may be affected by groundwater via the ingestion, inhalation, and dermal exposure routes. Indoor dust affects human consumers via the ingestion, inhalation, and dermal exposure routes. The consumer product may also affect all human and ecological receptors via the ingestion, inhalation, and dermal exposure routes.

### **Slide 79: Outdoor Exposure**

- Far-field
  - E.g., Pesticides
  - Inhalation, ingestion (water, produce, meat, fish, etc.)

Human exposure to a chemical may occur from sources within both the far-field and near-field. Fantke et al defined a far-field compartment as any location or environment that is distant from the use of a considered product, to and from which chemical transfers occur and within which removal processes occur. Far-field sources include environmental media (e.g., air, water bodies, or soil), biota (e.g., agricultural crops, animals and plants), or technological system (e.g., waste water treatment plants and landfills).

Diagram illustrating far-field outdoor exposures to emissions from a manufacturing source. Chemicals emitted via the air, water, or waste from a manufacturing facility may be: (1) inhaled from the air, (2) taken up by plants and animals from air and water contaminated by the chemical air emissions, (3) taken up from soil and biosolids contaminated by the chemical, (4) taken up by fish living in water contaminated by the chemical, or (5) by consuming contaminated food, animals, fish, or water.

A photo of a tractor spraying crops in a field and a factory emitting plumes of smoke are shown.

## Slide 80: Indoor Exposure

- Near-field
  - Dominant source of human exposure
  - highly dependent on
    - chemical properties
    - product characteristics
    - usage conditions
    - user behavior

A near-field compartment is defined as any indoor or near-consumer location or environment within the vicinity of the use of considered product to and from which chemical transfers occur and within which removal processes occur. Near-field sources refer to chemical exposures within a microenvironment, e.g., a residential building.

Exposures to near-field consumer product sources include both direct and indirect pathways (e.g., off-gassing of consumer products or dust ingestion). Exposures from near-field sources have been shown to be the dominant source of human exposure and are highly dependent on chemical properties, product characteristics, usage conditions, and user behavior.

Two diagrams: left-side is of a home to illustrate the factors considered for indoor exposure. The house dimensions (length, width, and height), floor covering, furniture, air replacement rate, and the exposure duration and frequency of the house occupants are considered. The right-side is a photo of someone applying lotion to their hand.

## Slide 81: Exposure Calculations – 1 of 2

- Inhalation
  - Inhalation rate \* concentration \* exposure duration
- Ingestion
  - Ingestion rate \* concentration in food/drink \* exposure duration
  - Concentration in food/drink requires additional calculations
- Dermal absorption
  - Permeability \* amount of contact \* exposure duration
- Internal organ specific
  - Adsorption, distribution, metabolism, excretion

## Slide 82: Exposure Calculations – 2 of 2

Calculation of Intake through Inhalation:

$$INH = \frac{C_a \times IR \times RR \times ABS \times ET \times EF \times ED}{BW \times AT}$$

Where INH = inhalation dose (mg/kg day)

$C_a$  = concentration in air (mg/m<sup>3</sup>)

IR = inhalation rate (m<sup>3</sup>/hr)

RR = retention rate of inhaled air (%)

ABS = percent absorbed into blood

ET = exposure time (hr/day)

EF = exposure frequency (days/year)

ED = exposure duration (years)

BW = body weight (kg)

AT = averaging period, i.e. period over which exposure is averaged:

For noncarcinogens use ED x 365 days/yr

For carcinogens use 70 yr x 365 days/yr

## Slide 83: Exposure Factors

Example calculation for the inhalation rate where the concentration in air = 0.05 milligrams per cubic meter, the inhalation rate = 0.25 cubic meters per hour, the retention rate = 100%, percent absorbed in blood = 50%, exposure time = 6 hours per day, exposure frequency = 330 days per year, exposure duration = 5 years, body weight = 16 kilograms, and averaging period = 5 times 365 = 1825 days. Using these factors the inhalation rate is 0.002 milligrams per kilograms-day.

**Slide 84: Exposure Assessment – Calculations for Ingestion of Contaminated Water and Ingestion during Recreational Activities**

Calculation of intake through ingestion of contaminated drinking water:

$$ING = \frac{C_w \times IR \times FI \times ABS \times EF \times ED}{BW \times AT}$$

Where ING = ingestion dose (mg/kg-day)  
 $C_w$  = concentration in water (mg/L)  
IR = average water ingestion rate (L/day)  
FI = fraction ingested from contaminated source  
ABS = percent absorbed into blood  
EF = exposure frequency (days/year)  
ED = exposure duration (years)  
BW = body weight (kg)  
AT = averaging period, i.e. period over which exposure is averaged:  
For noncarcinogens use ED x 365 days/yr  
For carcinogens use 70 yr x 365 days/yr

Calculation of Intake through Ingestion during recreational activities:

$$ING = \frac{C_w \times CR \times ABS \times ET \times EF \times ED}{BW \times AT}$$

Where ING = ingestion dose (mg/kg-day)  
 $C_w$  = concentration in water (mg/L)  
CR = contact rate (L/hr)  
FI = fraction ingested from contaminated source  
ABS = percent absorbed into blood  
EF = exposure frequency (days/year)  
ED = exposure duration (years)  
BW = body weight (kg)  
AT = averaging period, i.e. period over which exposure is averaged:  
For noncarcinogens use ED x 365 days/yr  
For carcinogens use 70 yr x 365 days/yr

## Slide 85: Exposure Assessment - Calculation for Ingestion of Contaminated Seafood

Calculation of Intake through Ingestion of contaminated seafood:

$$ING = \frac{C_w \times FIR \times BCF \times FI \times ABS \times EF \times ED}{BW \times AT}$$

- Where ING = ingestion dose (mg/kg-day)
- $C_w$  = concentration in water (mg/L)
  - FIR = average fish ingestion rate (kg/day)
  - BCF = bioconcentration factor
  - FI = fraction ingested from contaminated source
  - ABS = percent absorbed into blood
  - EF = exposure frequency (days/year)
  - ED = exposure duration (years)
  - BW = body weight (kg)
  - AT = averaging period, i.e. period over which exposure is averaged:
    - For noncarcinogens use ED x 365 days/yr
    - For carcinogens use 70 yr x 365 days/yr

### Slide 86: Exposure Assessment - Calculation for Dermal Exposure from Contacting Soil

Calculation of dermal exposure through soil contact:

$$DEX = \frac{C_s \times CF \times SA \times AF \times SM \times ABS \times EF \times ED}{BW \times AT}$$

- Where DEX = dermal exposure dose (mg/kg-day)
- $C_s$  = soil concentration (mg/kg)
- CF = conversion factor =  $10^{-6}$  kg/mg
- SA = skin surface area available ( $cm^2/event$ )
- AF = soil to skin adherence factor ( $mg/cm^2$ )
- SM = factor for soil matrix effects (%)
- ABS = percent absorbed into blood
- EF = exposure frequency (days/year)
- ED = exposure duration (years)
- BW = body weight (kg)
- AT = averaging period, i.e. period over which exposure is averaged:  
For noncarcinogens use ED x 365 days/yr  
For carcinogens use 70 yr x 365 days/yr

### Slide 87: Exposure Assessment - Calculation for Dermal Exposure from Contacting Personal Care Products

Calculation of dermal exposure from personal care products:

$$ADD_{abs} = \frac{DA_{event} \times SA \times EF \times ED}{BW \times AT}$$

- Where  $ADD_{abs}$  = Average daily dose (mg/kg-day)
- $DA_{event}$  = Absorbed dose (mg/cm<sup>2</sup>-event)
- SA = Skin surface area available for contact (cm<sup>2</sup>)
- EF = Exposure frequency (events/year)
- ED = Exposure duration (years)
- BW = Body weight (kg)
- AT = Averaging time (days)

## Slide 88: Exposure Assessment – Calculation for Absorbed Dose

Absorbed dose:

$$DA_{event} = K_p \times C \times t$$

Where  $DA_{event}$  = Absorbed dose (mg/cm<sup>2</sup>-event)  
 $K_p$  = Permeability coefficient (cm/hr)  
 $C$  = Concentration of chemical in vehicle contacting skin (mg/cm<sup>3</sup>)  
 $t$  = Time of contact (hours/event)

## Slide 89: Exposure Factors

- Water ingestion rate of approximately 2 Liters per day
- Food ingestion rate
  - Depends on
    - Food type
    - Preparation
    - Frequency of consumption
- Dermal exposure rate
  - Product specific

Three photos shown.

One photo is of a boy drinking a glass of water.

Source: <https://www.youtube.com/watch?v=72Jcvsk3A-g>

The second photo is a small girl about to eat at a large salmon.

Source: <http://www.tlc.com/tlcme/eating-fish-may-make-kids-smarter-and-help-them-sleep-better-at-night/>

The third photo is a woman applying a sun cream to her face.

Source: <https://www.allure.com/story/when-to-apply-sunscreen-before-or-after-moisturizer>

### **Slide 90: Sources of Exposure Data**

- Empirical, measured, or modeled estimates
- USEPA EXPOBOX
  - <https://www.epa.gov/expobox/about-exposure-factors-handbook>
- Exposure based on measured data has less uncertainty than estimates based on indirect information, such as modeling or estimation

### **Slide 91: Solvents in Consumer Products**

Screenshot of Table 17-5 from the 2011 US EPA Exposure Factors Handbook. Table 17-5 lists the exposure time for users of household solvent products only. The table lists the mean in minutes, the standard deviation, and percentile rankings for duration of use in minutes for several general product descriptions.

### **Slide 92: Solvents in Consumer Products**

Screenshot of Table 17-7 from the 2011 US EPA Exposure Factors Handbook. Table 17-7 lists the time exposed after duration of use for users of household solvent products only. The table lists the mean in minutes, the standard deviation, and percentile rankings for time exposed after duration of use in minutes for several general product descriptions.

### **Slide 93: Example of Exposure Factors**

Screenshot of Table 17-3 from the 2011 US EPA Exposure Factors Handbook. Table 17-3 lists the amount and frequency of use of various cosmetic and baby products. The table lists the amount of product per application in grams, the average frequency of use per day based on three types of surveys (CTFA, Cosmetic company, and Market Research Bureau), and the upper 90th percentile frequency of use per day based on three types of surveys (CTFA, Cosmetic company, and Market Research Bureau) for several general product descriptions.

### **Slide 94: Sample Results: Human Intake**

Bar graph showing the intake in two regions for four exposure pathways (indoor air, outdoor air, ingestion, and dermal). The exposure pathways are grouped by region on the x-axis while the intake in milligrams per kilograms-body weight is plotted along the y-axis. The intake values by exposure pathway in Region 1 are: approximately 0.04 milligrams per kilograms-body weight for indoor air, 0.02 milligrams per kilograms-body weight for outdoor air, 0.17 milligrams per kilograms-body weight for ingestion, and 0.02 milligrams per kilograms-body weight for dermal. The intake values by exposure pathway in Region 2 are: approximately 0.04 milligrams per kilograms-body weight for indoor air, 0.03 milligrams per kilograms-body weight for outdoor air, 0.04 milligrams per kilograms-body weight for ingestion, and 0.01 milligrams per kilograms-body weight for dermal.

### **Slide 95: Example of Exposure Scenarios by Life Cycle Segments for Asbestos in Brake Pads**

Screenshot of Table 6-1 on page 68 of the DTSC AA Guide.

Table 6-1 is an example on reporting results for exposure scenarios by life segments for asbestos in brake pads. The table has a header row for 5 columns: Life cycle segment, exposure frequency, exposure level, exposure duration, and exposure location. The table rows list information on exposure frequency, exposure level, exposure duration, and exposure location by life cycle segment. Ecological impacts are not considered in this example. Multiple locations may be listed for a given life cycle segment. For example, the end-of-life-management life cycle segment lists five exposure locations: brake remanufacturing facility, household hazardous waste facility, auto repair shops, brake repair shops, and auto salvage yards. For each exposure location, the exposure frequency, level, and duration is listed. The data listed for the brake remanufacturing facility, is as follows: (1) the frequency is listed as continuous during a work day; (2) the level list the permissible exposure limit of < 0.1 fiber per cubic centimeter of air and an excursion limit of 1.0 fiber per cubic centimeter; and (3) the exposure duration is listed as an 8-hour time-weighted average for the permissible exposure limit and a time-weighted average over 30 minutes for the excursion limit.

### **Slide 96: Exposure Levels**

Figure summarizing the information on page 65 of the DTSC AA Guide on the three types of exposure levels: individual, community, and environmental. The individual exposure level considers the types and extent of direct exposures that workers or consumers may encounter. The community exposure level considers exposure implications for a broader population, directly or indirectly. The environmental exposure level considers the exposure pathways that lead to the environment from various release points during the life cycle.

### **Slide 97: Tiered Approach to Exposure Assessment**

Figure 6-3 on page 76 of the DTSC AA Guide. Figure 6-3 is adapted from figure 3-1 from the [US EPA Air Toxics Risk Assessment \(ATRA\) Volume 1](#). The figure's title asks the question "What is the tiered approach to exposure assessment?" Three tiers are shown where the complexity and resource requirements, characterization of variability and/or uncertainty increases from Tier 1 to Tier 3. Tier 1 is considered a screening level approach where conservative exposure assumptions and simple modeling are used which incurs a low cost. Information gathered in Tier 1 is reviewed and refined before proceeding to Tier 2 where more realistic exposure assumptions and detailed modelling are used which incurs a moderate cost. Information gathered in Tier 2 is reviewed and further refined before proceeding to Tier 3 where probabilistic exposure assumptions and detailed site-specific modeling are used which incurs a high cost.

### **Slide 98: Exposure Assessment Tools**

Screenshot of Table 6-2 on page 200 of the DTSC AA Guide. Table 6-2 lists tools to assess target groups and exposure routes. The table has a header row for the following columns: Tools, human consumers for inhalation, ingestion, and dermal; human occupational exposure for inhalation, ingestion, and dermal; human children; human general population; and environment. Each row lists a tool and an "X" is placed in the column for the target group and exposure pathway it may be used. For example, CalTOX is listed as a tool that can be used to determine exposure for the general human population and the environment.

### Slide 99: Data needed for Exposure Models

- Exposure environment (e.g., residential building)
- Physicochemical properties (e.g., vapor pressure, Kow, water solubility)
- Chemical concentrations
  - in a medium (e.g., air, water)
  - at an exposure point (e.g., VOC in the breathing zone)
- Exposure factors
  - (e.g., drinking water consumption, inhalation rate)

While physicochemical properties are available for, or can be estimated for many chemicals, environmental fate data are often not available or are sparse for many consumer product chemicals. These properties can be used to determine or assess particular physical or toxicological hazards, bioavailability, transport, fate, degradation, persistence, bioconcentration, and cellular uptake.

### Slide 100: Exposure models

- Sources for necessary parameter values
  - Actual measurements
  - Fate and transport models
  - QSAR models (EPI Suite)
    - Chemical properties
  - EPA Exposure Handbook (EXPOBOX)
  - Survey data
  - Industrial Guides
  - MSDS
  - Literature

Careful with units!

### Slide 101: Risk Characterization

Diagram showing five areas to consider in risk characterization of a chemical: Use, release, Transport, Expose, and Hazard.

- Is there a human or ecological health risk?
  - Which populations?
  - Which exposure routes?
  - Which activities?

### Slide 102: Example: Human Risk

- Cancer Risk
  - Lifetime (70 yr) intake compared to cancer slope factor

Example bar graph of cancer risk for five regions where the regions are plotted along the x-axis and the risk in 1 in 100,000 is plotted along the y-axis. The cancer risk for each region has an error bar shown. The cancer risk for each region is: Region 1 = 2 in 1,000,000, Region 2 = 4 in a million, Region 3 = 3.5 in a million, Region 4 = 3 in a million, and Region 5 = 2 in a million.

- Non-Cancer Risk
  - Accumulated (10 yr) intake compared to RfD (reference dose)

Example bar graph of non-cancer risk for five regions where the regions are plotted along the x-axis and the non-cancer risk is plotted between 0 and 1.2 along the y-axis. The non-cancer risk for each region has an error bar shown. The non-cancer risk for each region is: Region 1 = 0.55, Region 2 = 0.9, Region 3 = 1.1, Region 4 = 0.6, and Region 5 = 0.4.

### Slide 103: Ecological Risk

- Predicted concentrations from fate and transport model compared with toxicity thresholds
  - NOEC, LOEC, LC50, EC50, etc.
- Risk determined by frequency of lowest threshold exceeded annually

Graph of concentration versus time. Time is plotted on the x-axis and concentration on the y-axis. The plot is an erratic line with two events where the threshold concentration is exceeded.

### Slide 104: Sample Results – Ecological Risk

Color-coded figure of ecological risk reported for five chemicals. The figure is a table where the column header row is the chemical name: Chemical A, Chemical B, Chemical C, Chemical D, and Chemical E. Eight rows correspond to the locations considered: (1) freshwater, (2) freshwater sediment, (3) marine, (4) marine sediment, (5) undeveloped soil, (6) urban soil, (7) agricultural soil, and (8) biosolids soil. The chemical risk is ranked as either high (red color), medium (orange color), low (yellow color), very low (green color), or no data (gray color). For freshwater, the chemicals are ranked as follows: Chemical A = low, Chemical B = high, Chemical C = medium, Chemical D = medium, Chemical E = low. No data is available on freshwater sediment for all the chemicals. For marine, Chemical A = very low, Chemical B = low, Chemical C = very low, Chemical D = low, Chemical E = very low. No data is available on marine sediment for all the chemicals. All chemicals have a very low risk for undeveloped soil and urban soil. For agricultural soil, Chemical A = very low, Chemical B = very low, Chemical C = very low, Chemical D = low, Chemical E = very low. For biosolids soil, Chemical A = very low, Chemical B = medium, Chemical C = low, Chemical D = medium, Chemical E = very low.

### Slide 105: Risk management

- Determine actions to reduce risk
  - Immediate (if risk is very high)
    - Restrict access to site
    - Recall product
  - Longer-term
    - Develop alternatives
    - Personal protective equipment
    - Inform consumer and control dose

## Slide 106: Uncertainty & Risk Assessment

Figure showing five graphical methods for presenting uncertainty. Example 1 is a 3D graph of the production volume at time “t” where time is on the x-axis, ENM volume is on the y-axis, and probability (density) is plotted on the z-axis. Example 2 is a color-coded bar for one peak from Example 1 to show the shares of application. Example 3 plots the time dependent application volumes based on Example 2 as three separate 3D graphs where time is on the x-axis and probability (density) is plotted on the z-axis. The first graph plots ENM mass in stock along y-axis, the second plots ENM mass in use along the y-axis, and the third plots ENM mass release along the y-axis. Example 4 shows two 3D graphs for the time dependent development of exposure: one for water and atmosphere and the other for soil and sediment where time is on the x-axis, released mass is on the y-axis, and probability (density) is plotted on the z-axis. Example 5 shows the environmental concentrations and risk for the two graphs in Example 4. Three 2D graphs are shown for the atmosphere, water, and soil and sediment. The environmental concentration is plotted along the x-axis and probability (density) is plotted along the y-axis for the three graphs. For the atmosphere, a bell curve for the predicted environmental concentration is shown. For water, a predicted environmental concentration curve and a predicted species sensitivity distribution curve is shown. The risk lies in the area where the two curves overlap. For soil and sediment, two predicted environmental concentration curves are shown. However, the curves do not overlap.

Reference: Giese, Bernd et al. “Risks, Release and Concentrations of Engineered Nanomaterial in the Environment.” *Scientific Reports* 8 (2018): 1565.

## Slide 107: Key Points

- Exposure and risk assessment can be used to support alternatives analysis.
- Toxicity assessment
  - From existing databases
- Exposure assessment
  - Release calculations
  - Concentrations & dose
    - Measured
    - From fate & transport models
  - Exposure factors
- Risk characterization
  - Consider likely exposure scenarios