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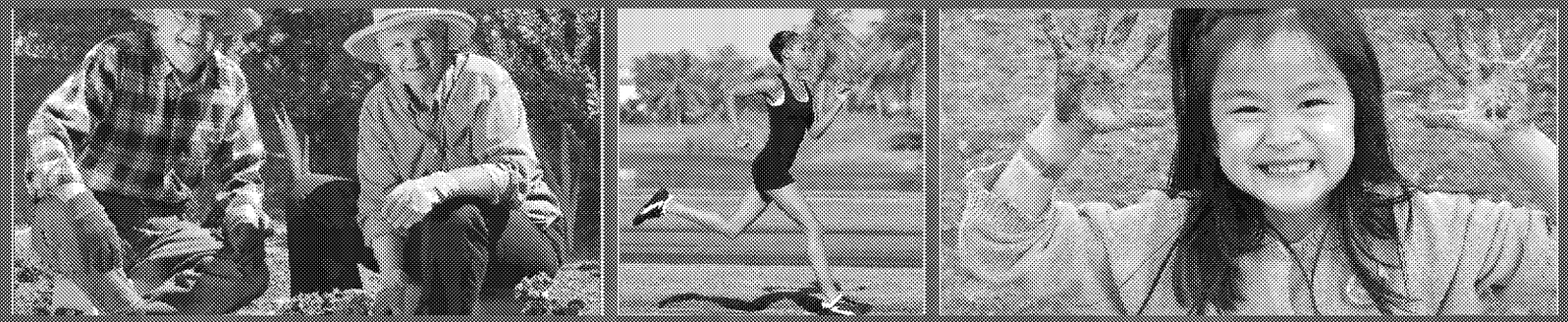
Progress for a Stronger Future

Approaches to Quantifying Exposure (EXA 402)



Risk Assessment Training and Experience

Exposure Assessment Course Series

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Risk Assessment Training & Experience

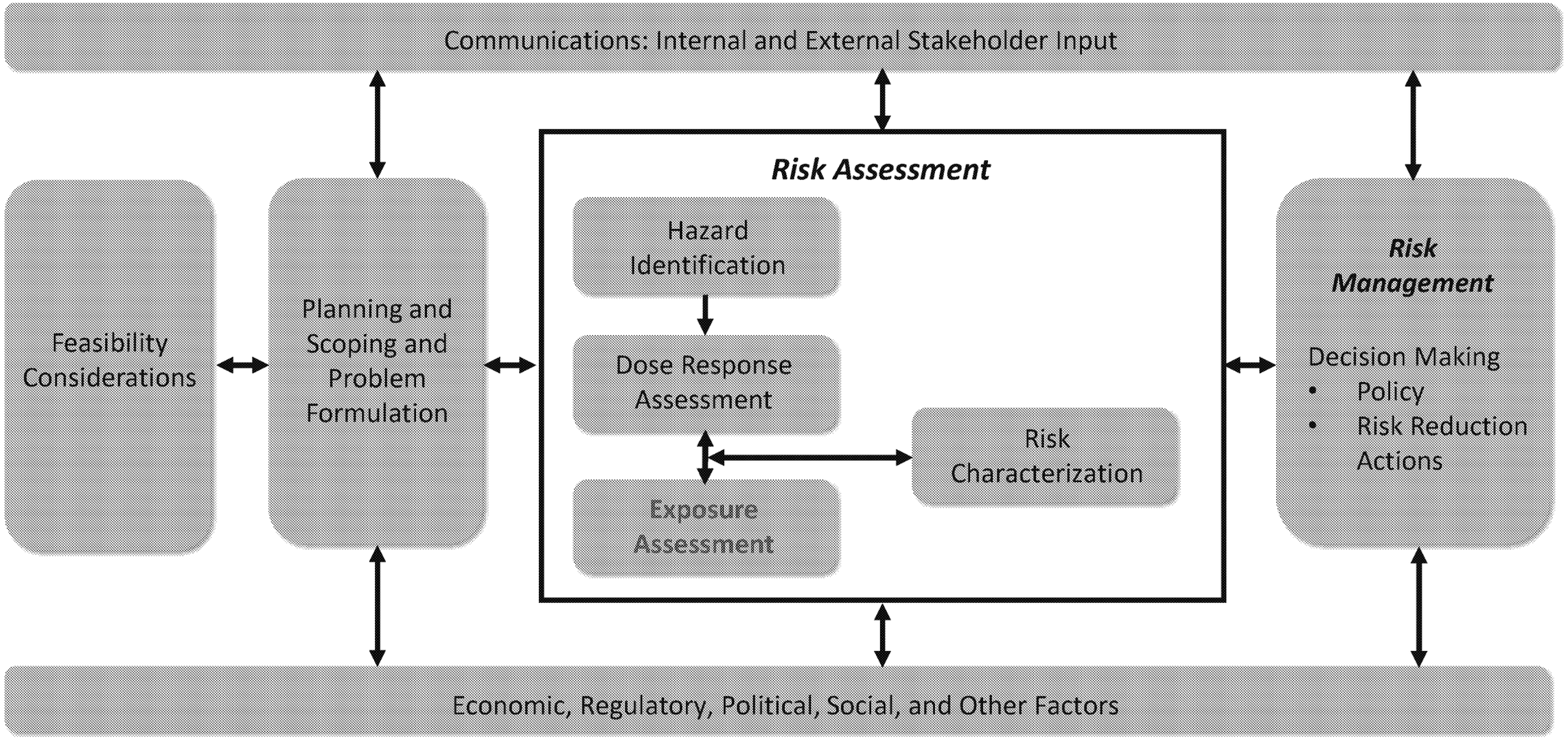
Disclaimer:
The views expressed are those of the speakers and do not necessarily represent the views or policies of the U.S. Environmental Protection Agency.

Learning Objectives

By the end of this course, you will be able to:

- Explain the different methods for quantifying exposure and dose
- Understand the relationship between exposure and hazard within the risk assessment paradigm

Overview of Exposure Assessment in Risk Assessment Process



Adapted from NRC (2009)

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Feasibility Considerations

Planning and Scoping

- Exposure Assessment Goals and Scope
- Overarching Considerations
- Stakeholder Involvement
- EPA's Tribal Program and Networks
- Peer Review

Problem Formulation

- Individuals, Lifestages, Groups, Populations
- Conceptual Model

Exposure Assessment Analysis Plan

- Data Sources, Gaps, Limitations and Quality Objectives
- Exposure Scenarios

Feasibility

- Science
- Cost
- Time
- Assessment constraints
- Sampling capabilities

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SCOPE OF THE EXPOSURE ASSESSMENT

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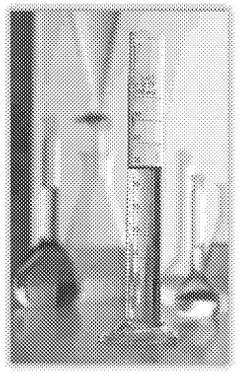
What is the Scope of the Assessment?

"Scoping…involves defining the elements that will or will not be included in the risk assessment. These include the stressors, sources, pathways, routes, populations, and effects or assessment endpoints to be evaluated."

EPA's Framework for Cumulative Risk Assessment, 2003

- **Scope** can be affected by a range of issues

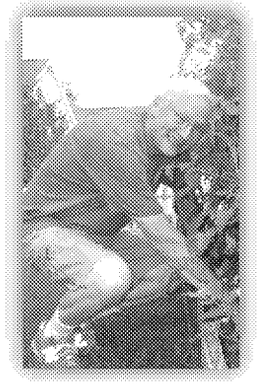

Chemical Stressors

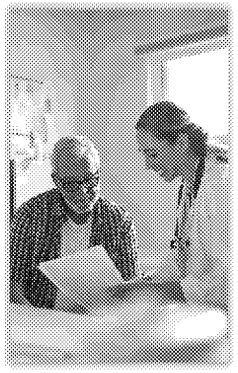
Non-Chemical Stressors

Sources

Pathways

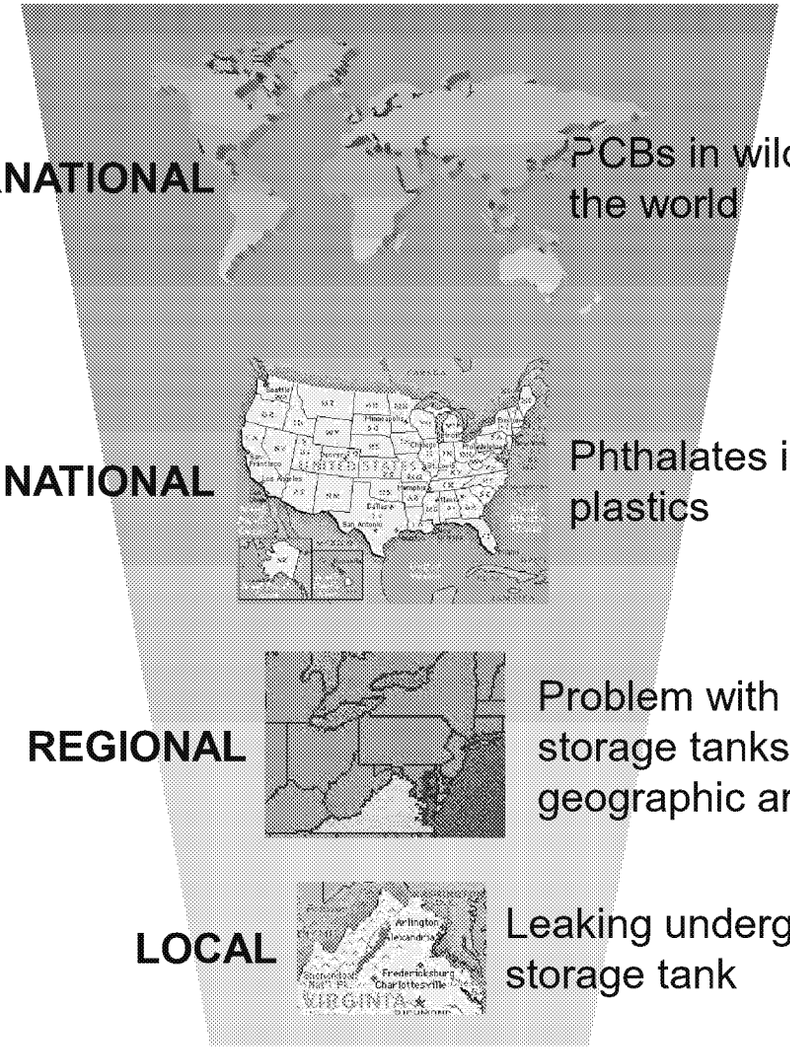
Routes


Population


Effects

- **Tiered approach** facilitates iterative decision making

What is the Geographic Scale?



- Scale also influenced by:
  - Receptor population(s)
  - Industries or areas affected
  - Remediation options
  - Legacy or lifetime exposures
  - Cost
  - Time

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Demographics: Who Are the Receptors?

Human Receptor: Any biological entity (e.g., a human, human population, lifestage within a human population) that receives an exposure.

EPA's Guidelines for Human Exposure Assessment, 2019

Ecological or Wildlife Receptor: The ecological entity exposed to the stressor. May refer to tissues, organisms, populations, communities, and ecosystems.

EPA's Guidelines for Ecological Risk Assessment, 1998

Susceptibility: An increased likelihood of an adverse effect, often discussed in terms of relationship to a factor that can be used to describe a human population (e.g., lifestage, demographic feature, or genetic characteristic)

EPA's Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens, 2005

Examples:

- **Highly exposed populations**
  - Individuals who eat fish or produce that is contaminated by the stressor
  - People who are occupationally exposed
  - Certain product uses
- **Potentially susceptible populations**
  - Children and the elderly
  - Women of child-bearing age
  - People with compromised immune systems

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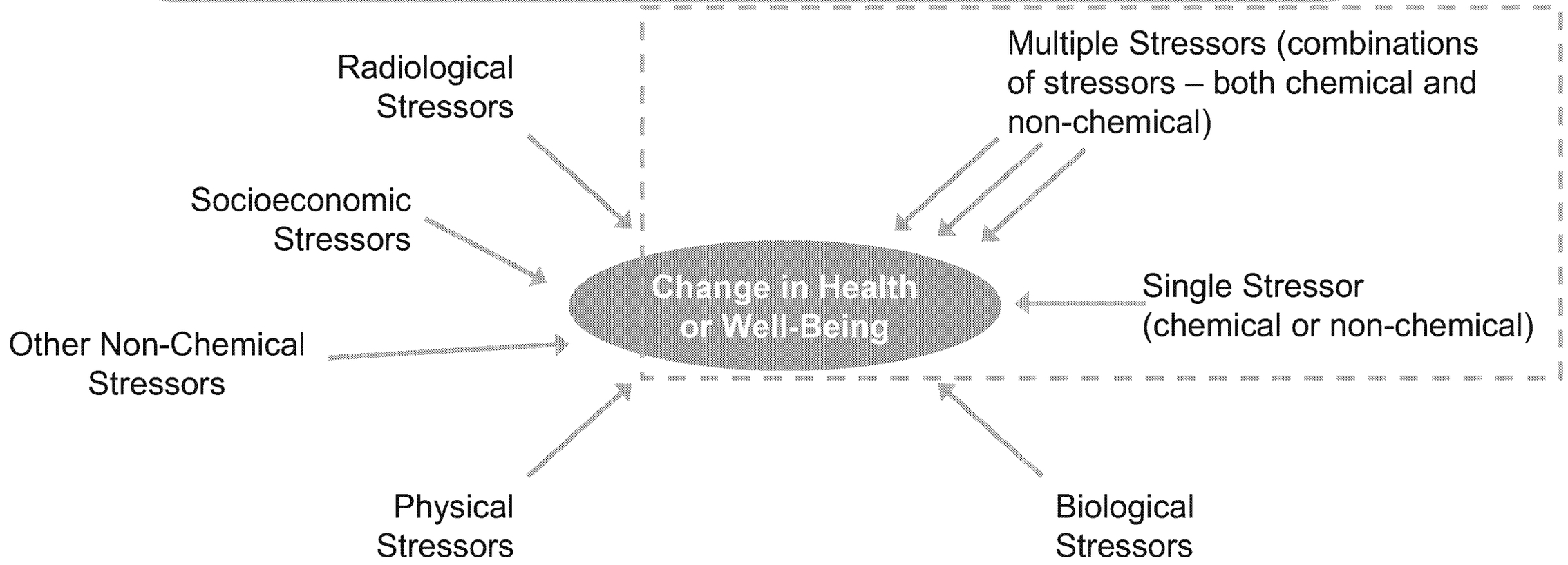
What are Stressors?

Stressor: Any chemical, physical, social or biological entity that induces a change (either positive, negative, or neutral) in health or well-being (either now or into the future).

EPA's Guidelines for Human Exposure Assessment, 2019; Tulve et al., 2016



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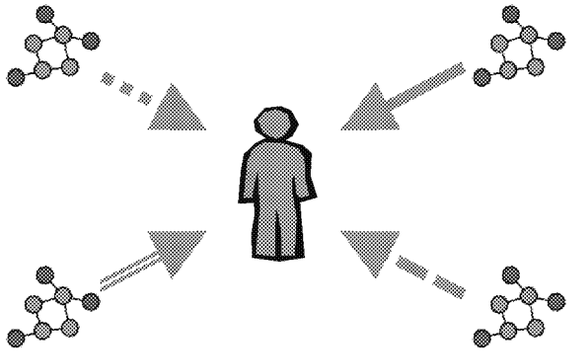
Aggregate and Cumulative Exposures

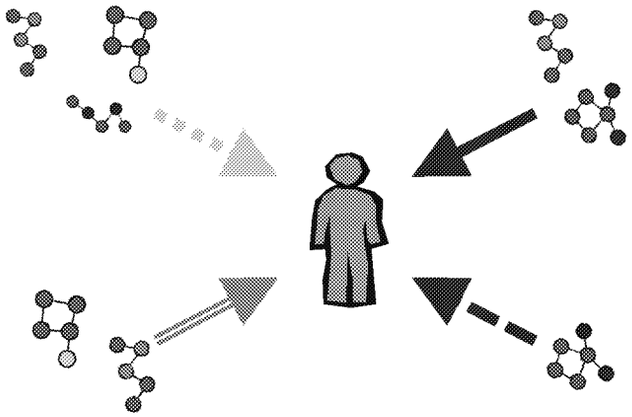
Aggregate Exposure:

- Exposure to a **single chemical** from multiple sources and exposure pathways

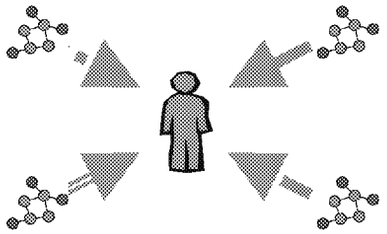


Cumulative Exposure:

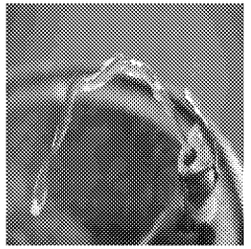
- Exposure to **multiple chemicals** from multiple exposure pathways



Understanding Aggregate Exposure



- Aggregate exposure assessments evaluate combined exposure to a **single chemical** across **multiple routes and pathways**
- **Example:** Aggregate exposure assessment for pesticides
  - Acute and chronic exposure to residues in food
  - Residues in water
  - Residential exposures to consumer products, consumer articles, and building products



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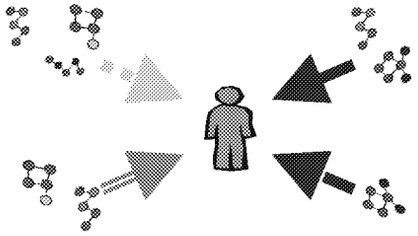
Understanding Cumulative Exposure

- Cumulative exposure assessments evaluate the impact of **multiple chemicals** with **multiple routes and pathways** of exposure
  - Not simply a sum of aggregate exposure assessments – individual interactions must be considered
- **Examples:**
  - Exposure to multiple pyrethroid pesticides with same mechanism of action
  - Air toxics emissions from point sources



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TIERED APPROACH TO EXPOSURE ASSESSMENT

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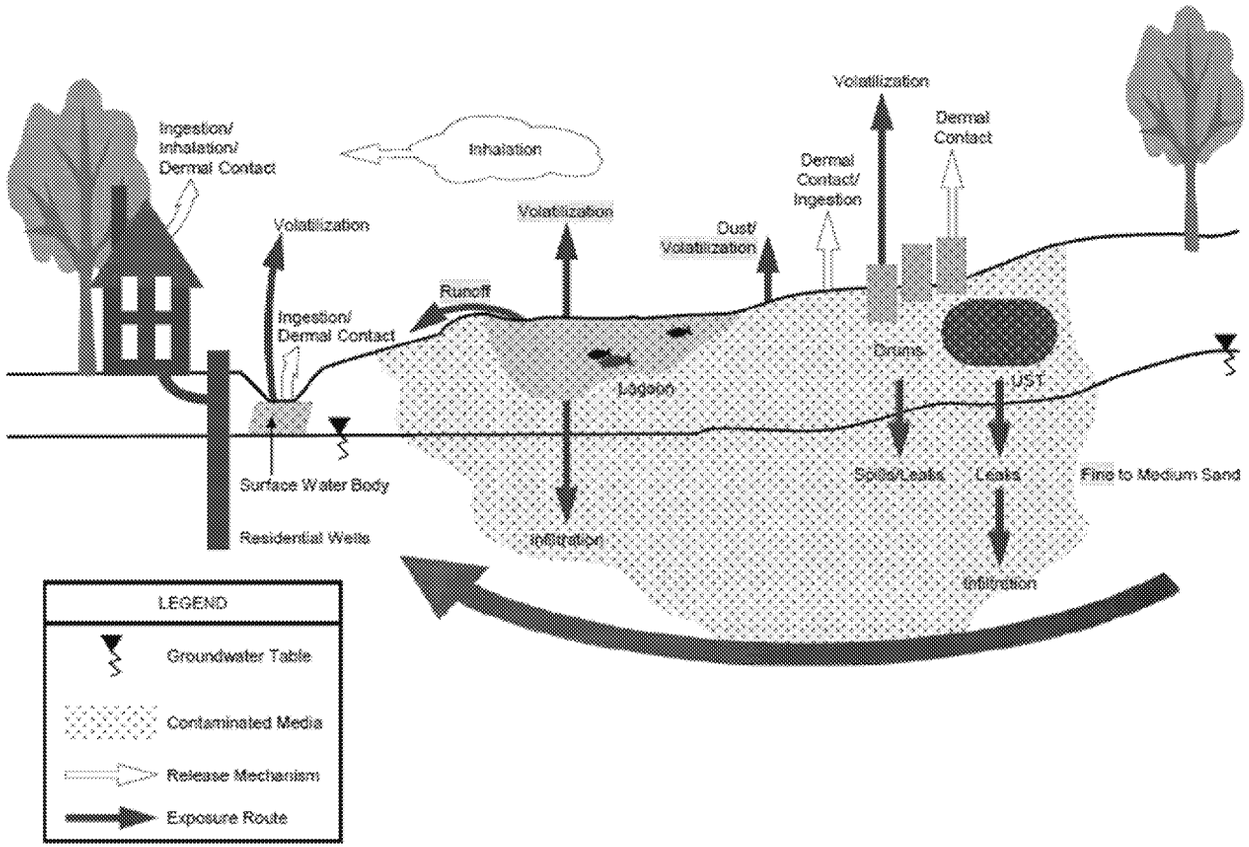
Conceptual Site Model

- Planning tool used for various types of exposure assessments.
- Identifies known or potential sources of contamination, release mechanisms and receptor routes; all potential exposure pathways, and the media and receptors associated with each.
- Helpful tool to organize available information to identify missing data or uncertainty.
- Used to determine assessment-specific data needs.



From Figure 3-3, Guidelines for Human Exposure Assessment, 2019

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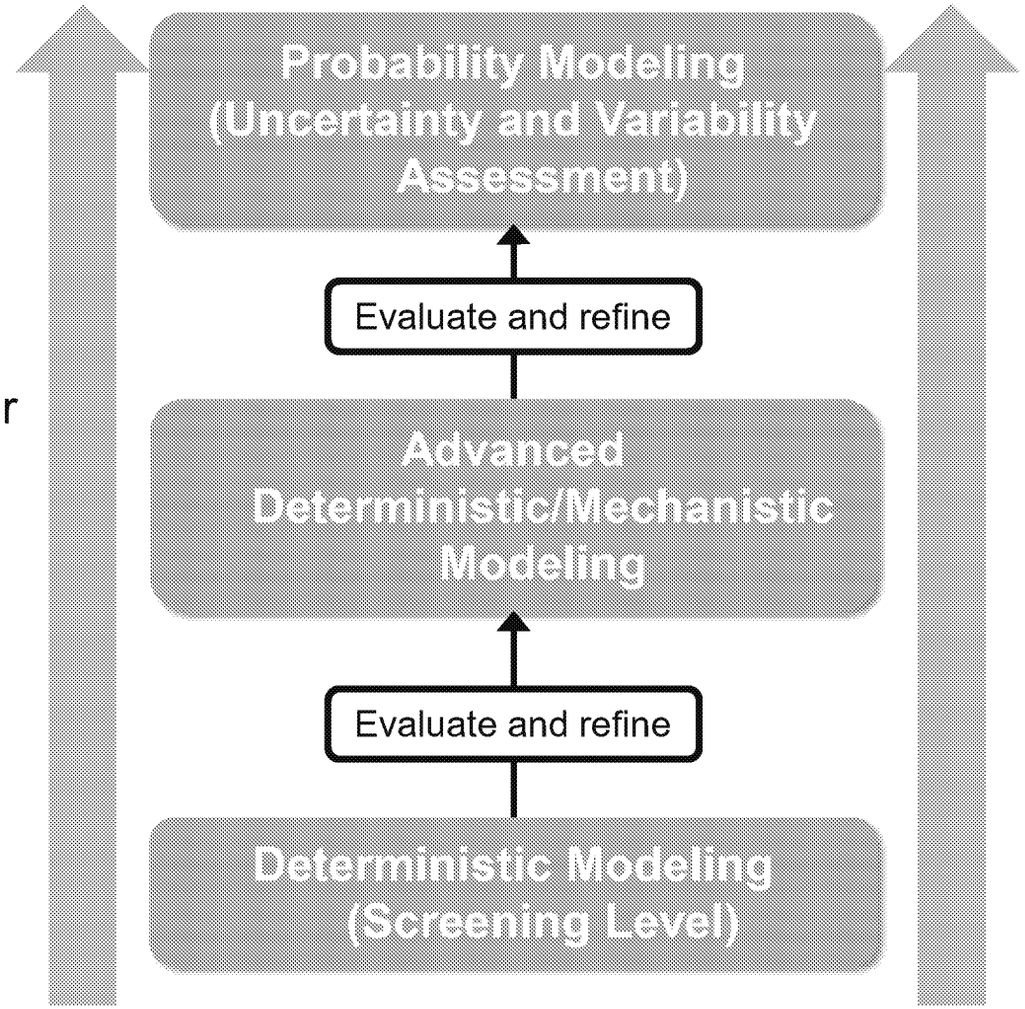
Tiered Approach to Exposure Assessment

Increasing Complexity for Exposure, Risk, and Uncertainty Characterization



Increasing Regulatory Significance and Greater Decision-Making Needs

Adapted from Özkaynak et al. (2011) and EPA (2019)

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Determining Whether Data Meet Assessment Factors

- Data needed for an assessment depends on the approach
- Once approach is determined, assessors will need to:
  - Determine data needs and develop DQOs for the data
  - Evaluate quality and appropriateness of existing data against the DQOs
  - Identify data gaps and impact of gaps
  - Collect new data
- A QAPP is developed for both new and existing data

Data Quality Objective (DQO)

- Describe degree of uncertainty project team is willing to accept
- Outline minimum performance and acceptance criteria for data used in assessment

Quality Assurance Project Plan (QAPP)

- A written document that describes quality assurance procedures, quality control specifications, other technical activities
- Outlines activities to ensure the results of the project will meet the specifications

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Screening-Level (Deterministic) Exposure Assessment

Characteristics:

- Preliminary evaluation tool
  - Tools include deterministic and semiquantitative (e.g., presence/absence) models, conservative data and default assumptions
- Can produce quantitative, conservative estimate with available data and/or models
- Results useful for general comparisons or prioritization
  - Simple, determines whether or not there may be a concern
- Minimizes unnecessary time and expense
- Depending on the needs of the assessment, a screening level assessment may lead to more complex assessments

Example:

- Do strawberries contain measurable levels of pesticides?
- Screening-level assessment used to determine if more modeling is needed

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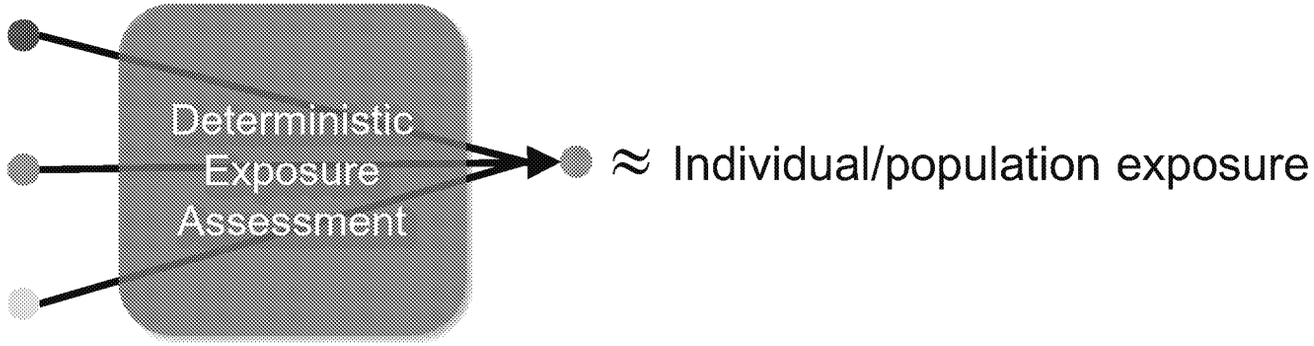
Refining an Exposure Assessment

	Screening-Level Assessments	Probabilistic Assessments
Measurements	• Readily available measurement data • Release estimates based on generic emission factors	• Site-specific measurement data • Emissions monitoring data
Inputs	• Default parameters • Generic or conservative model parameterization • Generic or conservative exposure assumptions	• Site-specific parameterizations
Models	• Simple models (screening-level, deterministic)	• More complex models (probabilistic)

Deterministic Exposure Assessment

- Use **point estimates** for input parameters to quantify exposure for a population or individual
- Resulting exposure estimate is also a point estimate (e.g., central tendency, reasonable maximum exposure, maximally exposed individuals)
  - Different programs use various point estimates (e.g., Superfund uses reasonable maximum exposure and Office of Air and Radiation uses maximally exposed individuals)
- Straightforward and relatively economical
- Limited characterization of uncertainty or variability with multiple deterministic runs



Probabilistic Exposure Assessment

Characteristics:

- Uses **probability (frequency) distributions** for certain influential parameters to quantify exposure and account for variability
- Describes the range of values and estimates the likelihood that the values may occur for random variables
- Used to understand uncertainty and variability
- Resource documents:
  - Guidance on conducting probabilistic assessments in EPA Risk Assessment Guidance for Superfund (RAGS Volume III Part A)
  - Air Toxics Risk Assessment (ATRA)
  - Literature on Stochastic Human Exposure and Dose Simulation (SHEDS) model and other probabilistic models

Example:

- Monte Carlo simulation
  - Common sampling approach to generate probabilistic results

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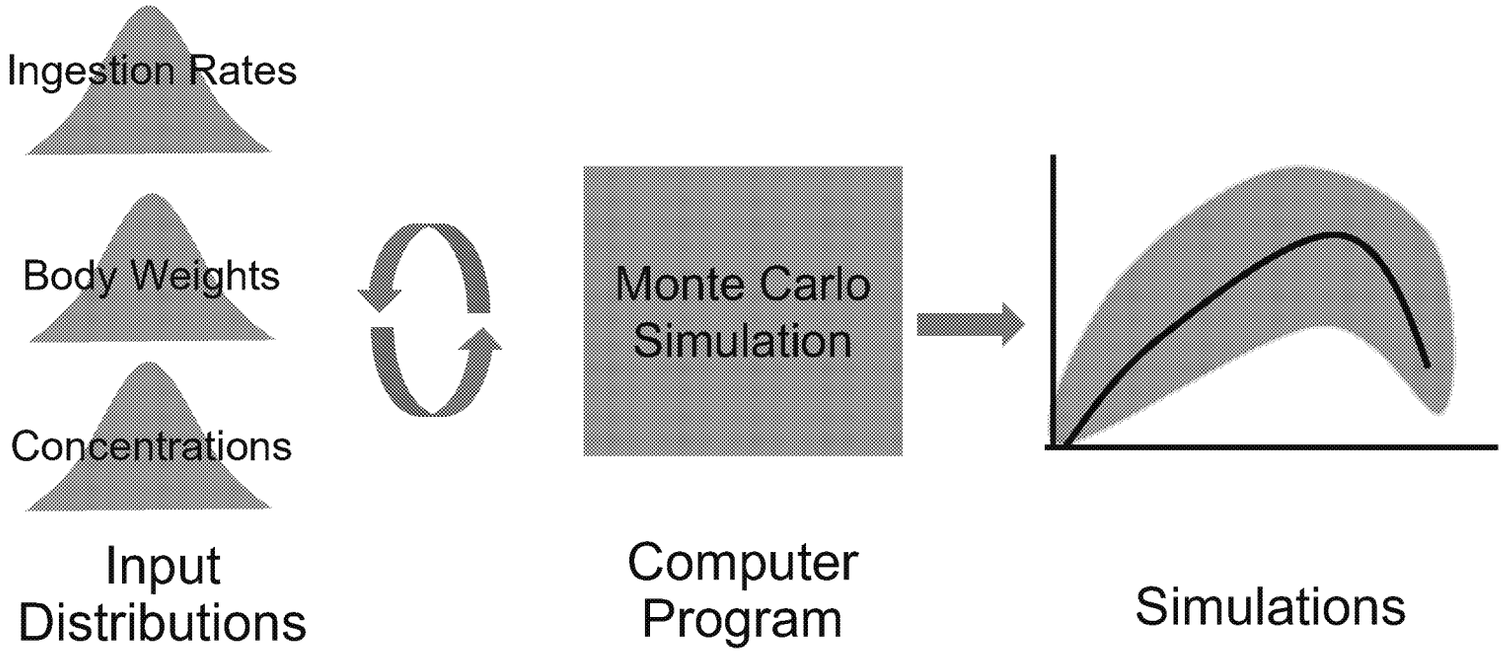
What is a Monte Carlo Simulation?

"A technique for characterizing the uncertainty and variability in exposure estimates by repeatedly sampling the probability distributions of the inputs and using these inputs to calculate a range of exposure values."

EPA's RAGS Volume III Part A, 2001

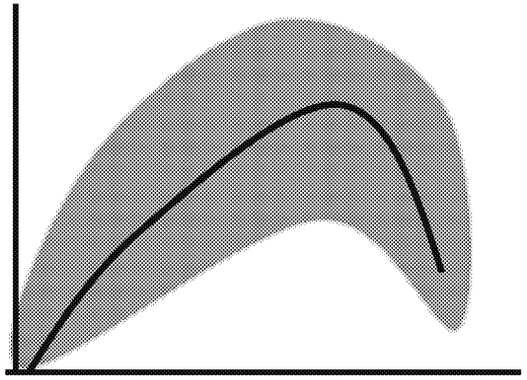


The range of values represents the entire exposed population. The assessor must select a point on the resulting distribution to use as the basis for their decision (e.g., levels protective of 95% of the population)

Source: U.S. EPA "Approaches for the Application of Physiologically Based Pharmacokinetic (PBPK) Models and Supporting Data in Risk Assessment (Final Report)," 2006.

Monte Carlo and Probabilistic Methods

- Require more data than deterministic approaches
- Require development of input parameters and possibly peer-review
- Allow for better estimates of uncertainty and variability
- Use of probabilistic methods depends on the assessment goals



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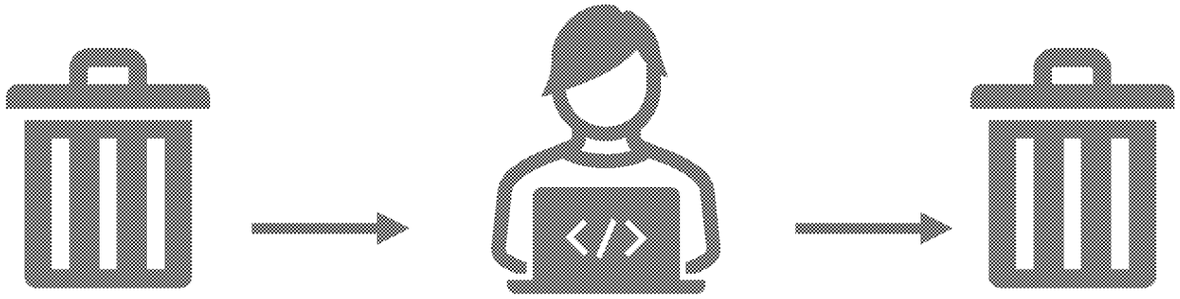
Garbage In, Garbage Out

- A great model cannot improve bad data; output is only as good as the input
- Model outputs are only as accurate as the data used to build them
- Sophisticated models or Monte Carlo simulations cannot transform low-quality data to be more accurate or precise



Sources of Data Uncertainty

Data uncertainty refers to a lack of data or an incomplete understanding of the context of the risk assessment decision. It can be either qualitative or quantitative.

Uncertainty can be reduced or eliminated with more or better data.

- **Sources of data uncertainty:**
  - Descriptive errors
  - Aggregation errors
  - Professional judgment errors
  - Incomplete analysis
  - Measurement or sampling errors
  - Model uncertainty (e.g., relationship errors, parameter uncertainty, selection of incorrect model, modeling errors)

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STATISTICAL DESCRIPTORS TO DESCRIBE MEASUREMENTS

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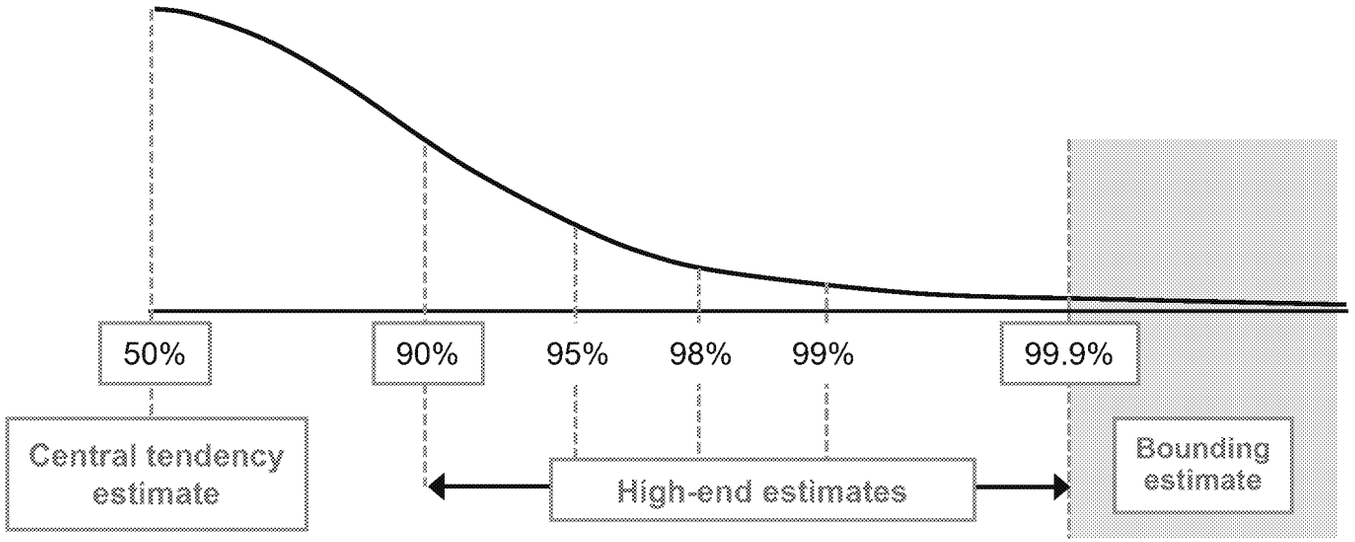
Use of Statistical Descriptors to Describe Measurements

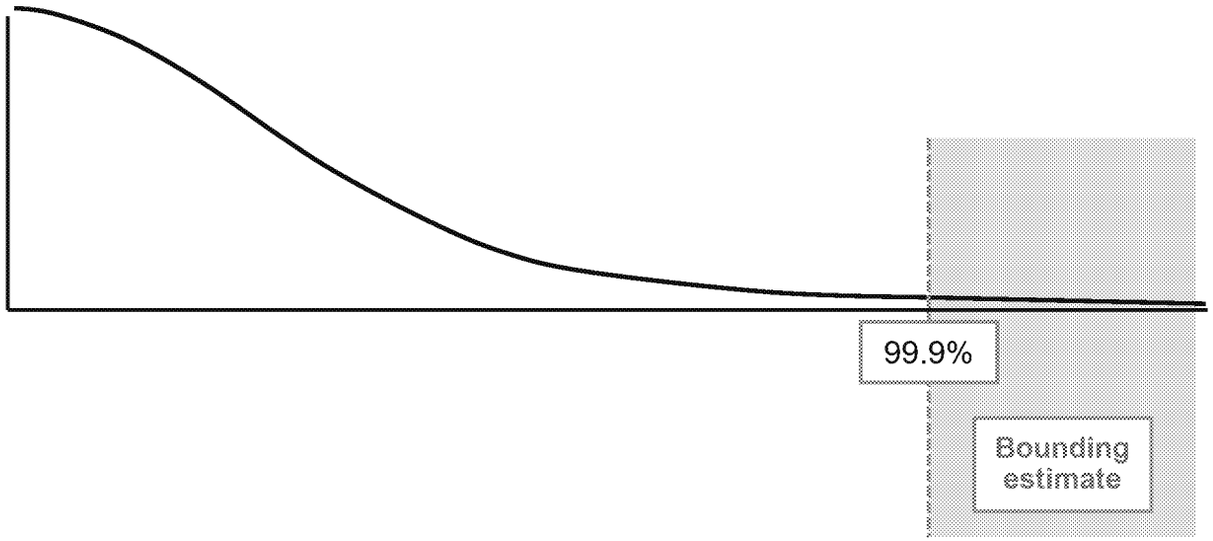
- **Statistical descriptors** are estimates of specific points on the distribution of measurements
  - Based on selected parameter values
  - May be for individual or population estimates
  - Help assessors communicate with risk managers and others
  - May be developed to support regulatory decisions



Typical percentiles of exposure

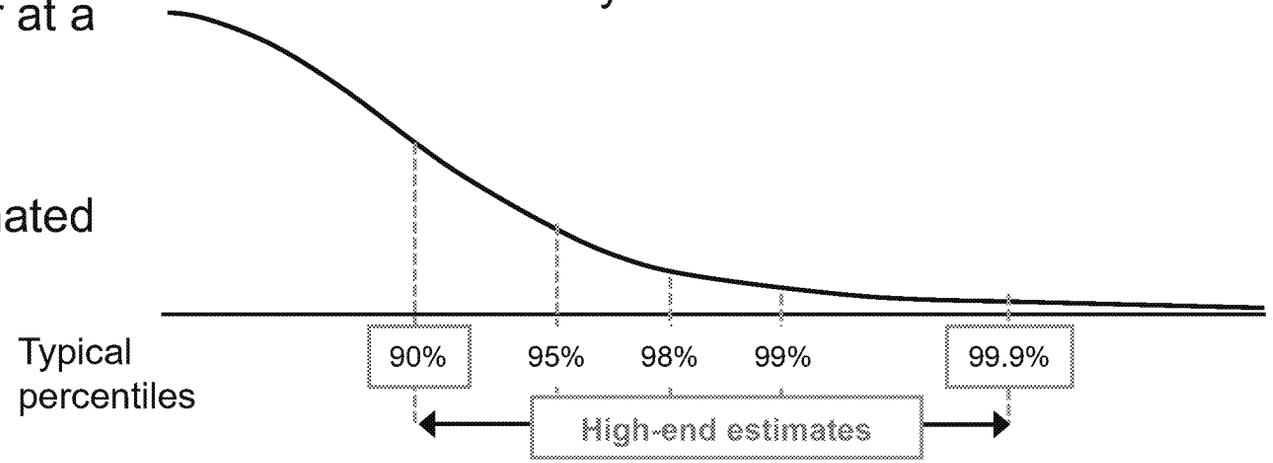
Bounding Estimates

- **Bounding estimates** capture highest possible exposure or theoretical upper bound estimate
  - Useful for rapid screening estimate
  - Uses highest intake rates, exposure frequency and distribution; and average body weights for estimate



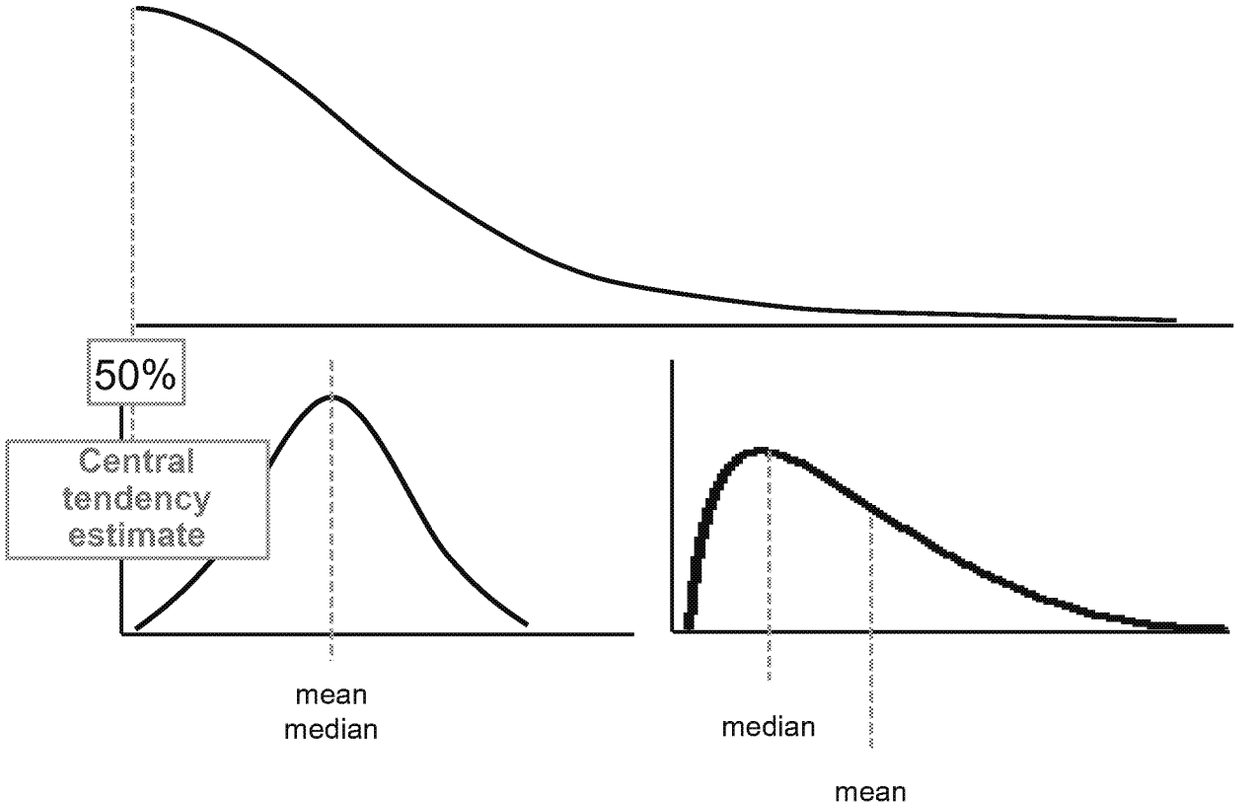
High-End Estimates

- **High-End Estimates** – at or above 90th percentile of population distribution (EPA, 2019)
  - Combination of high and central tendency inputs
  - More realistic than bounding estimate
- **Reasonable Maximum Exposure (RME)** – from EPA 2001 and 2019
  - Used in Superfund remediation decisions
  - Highest exposure reasonably likely to occur at a Superfund site
  - Generally, represents the 90th–99.9th percentile of the exposure distribution estimated from a probabilistic risk assessment
- **Reasonable worst-case exposure**
  - Used for the maximum possible exposure occurring when all events that can plausibly occur to maximize exposure occur.
  - Does not include extreme values due to accidents
- **Maximum exposure range** (above the 99th percentile) – from EPA 2019
  - As exposure estimate moves higher in the range, level of uncertainty rises



Central Tendency Estimates

- Provides an **average** or **typical estimate** for an individual, population or specific scenario. Derived using:
- **Arithmetic mean**
  - Uses average values for all factors
  - Representative of "average" receptor or group
- **Median** exposure
  - Corresponds to 50th percentile exposure
  - Useful when data are in a lognormal distribution



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THREE APPROACHES FOR ESTIMATING EXPOSURE

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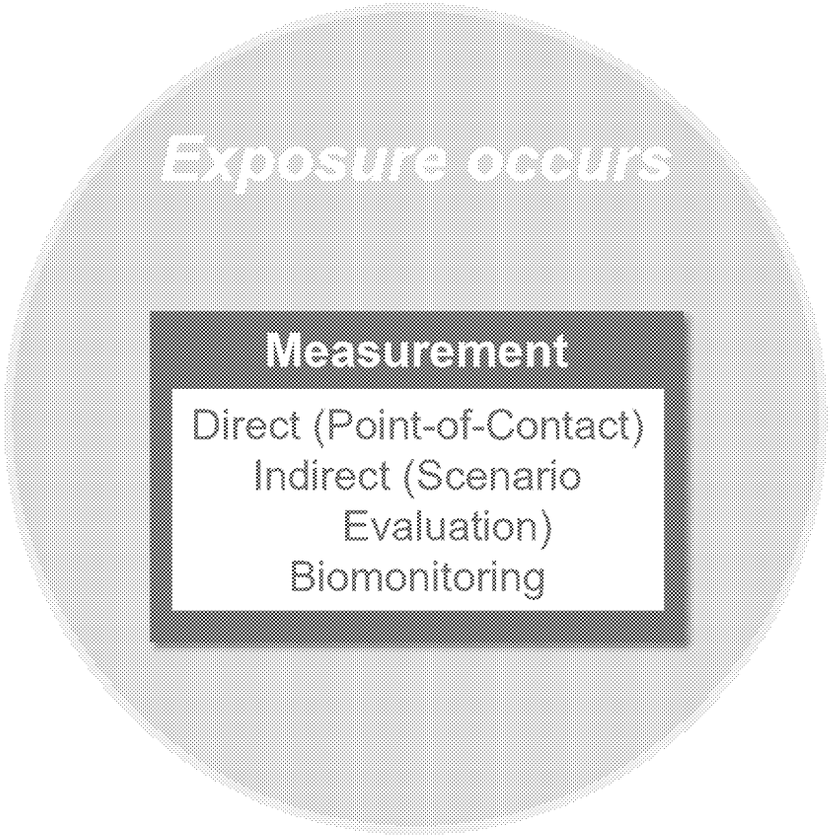
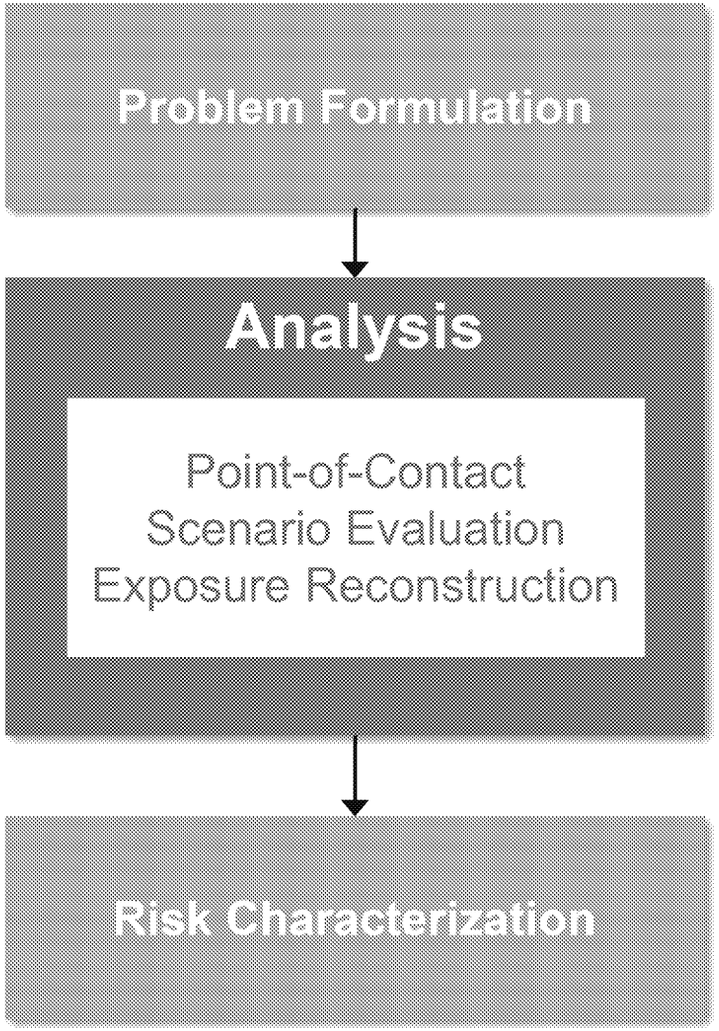
Approaches for Estimating Exposure





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POINT-OF-CONTACT (DIRECT MEASUREMENTS) FOR EXPOSURE ASSESSMENT

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Point-of-Contact (Direct Measurement) Methods

Point-of-contact methods measure the contact of the person with the chemical concentration in the exposure medium over an identified period.

EPA's Guidelines for Human Exposure Assessment, 2019

- Examples:
  - Dosimeters
  - Personal inhalation monitoring (breathing zone)
  - Personal dermal monitoring
  - Food and beverage consumption

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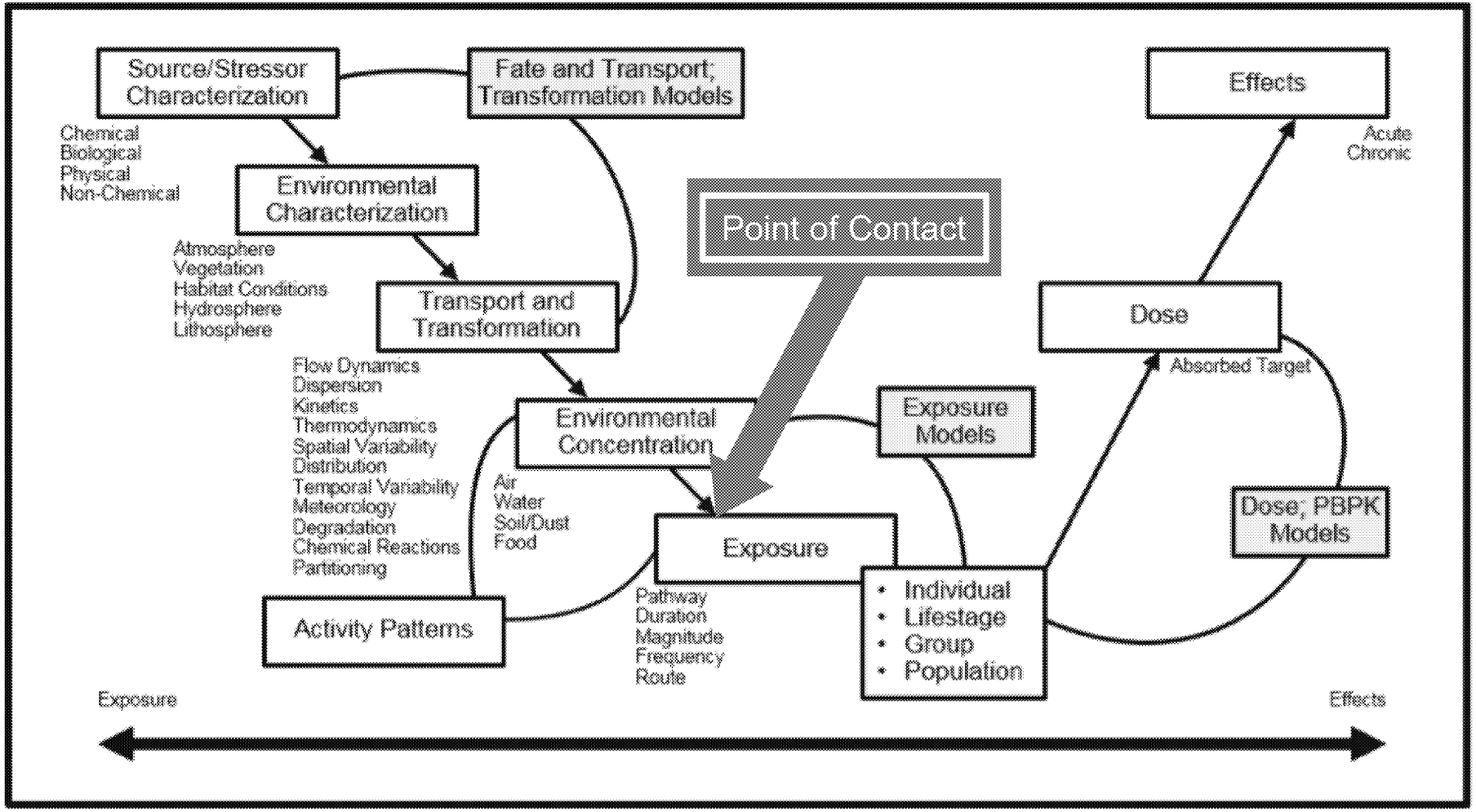
Where Does Point-of-Contact Fit?



Note: PBPK = physiologically based pharmacokinetic

Adapted from NRC (1983); NRC (1997)

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Point-of-Contact Methods: Strengths and Weaknesses

Strengths:

- Measures exposures directly
- Representative of individual exposures
- Most accurate method for quantifying exposure

Weaknesses:

- Expensive
- Not source-specific
- Not available for all chemicals
- Relies on accuracy of the device, the person operating it and the strength of analytical methods

Direct Measurements of Inhalation Exposure

- Monitors are typically compact and located close to the breathing zone of the individual
  - Passive monitoring:
    - Uses sorption method
    - More appropriate for long-term exposure
  - Active monitoring:
    - Small air pump draws air through a filter, packed tube or similar device.
    - Requires power (either battery or electricity)

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Direct Measurements of Dermal Exposure

- Wide range of methods and devices for measuring dermal exposure
  - Patches – used for pesticides, metals, dusts
  - Whole-body dosimeters – radiation badges, coveralls, full-length cotton underwear
  - Removal – rinsing, wiping, and tape strips to collect contaminants from skin
  - Optical methods – fluorescent tracers

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Direct Measurements of Ingestion

- Duplicate diet collection
  - Individuals collect duplicate samples of all foods consumed in a given period
  - Samples are analyzed to measure concentrations of chemicals of interest
  - Provide information on:
    - Concentration of chemical in food
    - Intake rate of chemicals of interest, per bodyweight of participant

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EXAMPLE: An EPA Point-of-Contact Assessment

- Children's Total Exposure to Persistent Pesticides and Other Persistent Organic Pollutants (CTEPP) Study
  - One of the largest studies on children's exposure to chemicals
  - In 2000-2001, measured 40+ chemicals in homes and day care centers in NC and OH.
    - **Media:** Food, beverages, drinking water, indoor and outdoor air, hand wipes, house dust, classroom dust, play area soil, floor wipes, and urine
    - **Targeted Chemicals:** PAHs, organophosphate pesticides, phthalate esters, phenols, and PCBs

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EXAMPLE: CTEPP Results

- Low levels of many chemicals were found in both homes and day care centers
- Most frequently detected chemicals are those commonly used in the home, found in products within the home, or from common processes such as combustion
- For children, ingestion of food was the dominant route of exposure to the most frequently detected chemicals
- Project Report available at EPA webpage

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SCENARIO EVALUATION (INDIRECT) FOR EXPOSURE ASSESSMENT

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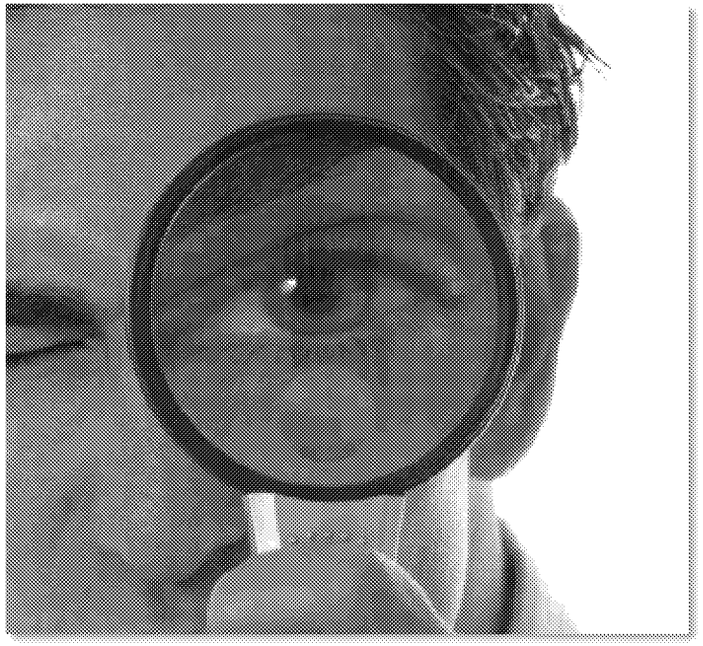
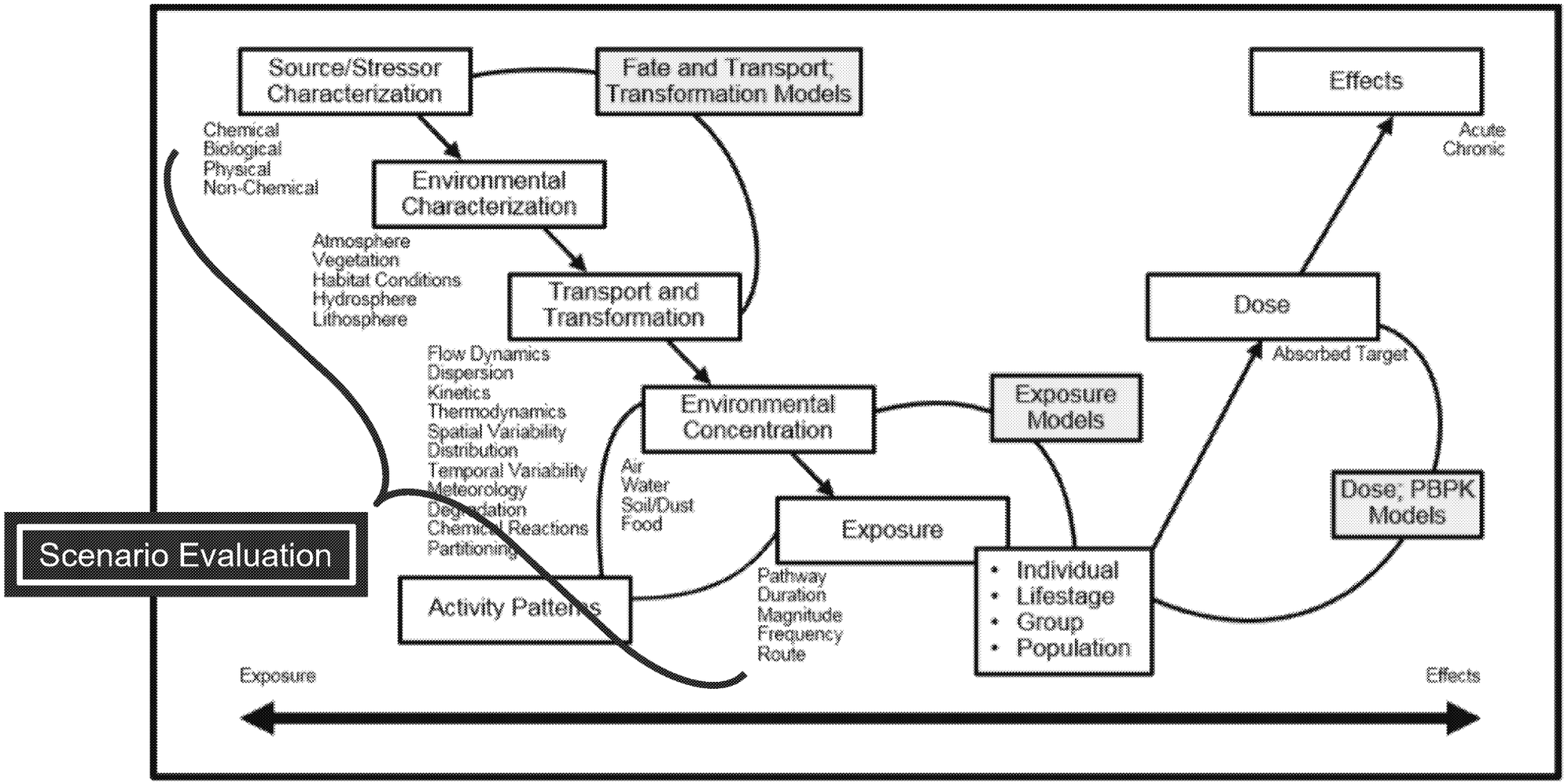
Scenario Evaluation (Indirect) for Exposure Assessment

- **Scenario evaluation** estimates exposure by developing an exposure scenario to combine information on chemical concentration, time-of-contact information, and data on exposed persons
- **Exposure scenario**: A set of facts, assumptions, and inferences about how exposure takes place that aids the exposure assessor in evaluating, estimating, or quantifying exposure
  - Characterized by:
    - Setting
    - Chemical characteristics and sources
    - Exposure pathways and routes
    - Environmental and exposure media
    - Intake and uptake rates
    - Characteristics of exposed population
- Will be discussed in detail in EXA 403



Where Does Scenario Evaluation Fit?



Note: PBPK = physiologically based pharmacokinetic

Adapted from NRC (1983); NRC (1997)

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Scenario Evaluation: Strengths and Weaknesses

Strengths:

- Can be economical, depending on the scale of the study
- Well-suited to evaluating proposed actions
- Can be done with limited data

Weaknesses:

- Simplification of the exposure scenario leads to less accuracy
- Limited data needed for approach means more uncertainty

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Implementing Scenario Evaluation

Assumptions:

- Data are representative of the exposed population
- Data on chemical fate and transport correspond to actual exposure scenario

Data Requirements:

- Chemical concentrations from sampling, or fate and transport modeling results
- Population statistics, including sensitive population groups
- Time of contact and routes of exposure for each chemical and receptor

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EXAMPLES: Types of Models Used

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

Key Questions in Model Selection

What do you need to consider when selecting your model?

- Objectives of assessment
- Appropriateness for your scenario
- Data needs
- Previous uses and outcome predictions
- Logistics of using the model (appropriate expertise)
- Peer review
- Regulatory considerations that may influence choice of model

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EXAMPLE: Fate and Transport Models

- Simulate movement and transformation of contaminants in the environment
- Predict concentrations in:
  - Sediment, surface water, groundwater, drinking water

AERMOD
(AMS/EPA Regulatory Model)

Air dispersion model that simulates fate of airborne pollutants and concentrations at different locations

EXAMS
(Exposure Analysis Modeling System)

Screening-level model that estimates pesticide concentrations in drinking water and surface water bodies

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EXAMPLE: Exposure Models

- Predict exposures by inhalation or multimedia based on environmental concentrations, population characteristics, exposure factors, and activity patterns

APEX
(Air Pollutants Exposure Model)

Estimates population-level exposures and doses to air pollutants for general population and sensitive groups at local, urban, and metropolitan levels

DEEM
(Dietary Exposure Evaluation Model)

Estimates individual or population-level dietary exposures and doses to pesticides and pesticide residues in residential settings

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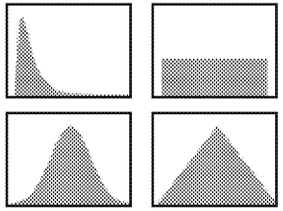
SHEDS: A Multimedia, Multipathway Exposure Model

Input Databases

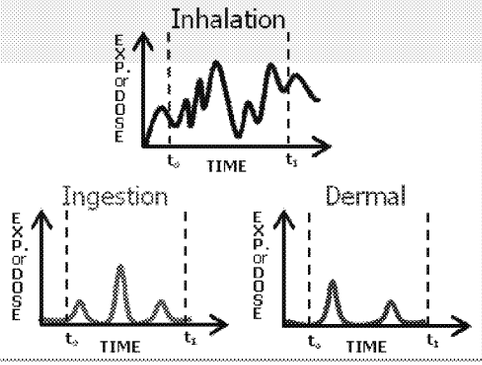
- Census
- Human Activity
- Residues
- Concentrations
- Recipe/Food Diary

Exposure Factor Distributions



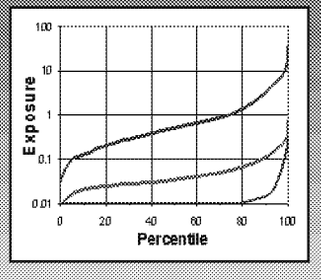
Algorithms

- Calculate Individual Exposure/Dose Profile

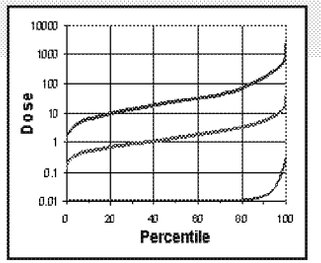


Output

- Population Exposure



- Population Dose



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The SHEDS Models

- The SHEDS family includes multiple models at various levels.

SHED-High throughput (HT)

- Screening level
- Cross-sectional
- Considers stressor exposure at home from three types of sources: products, articles, and food.
  - *Products*: have a time and frequency of use, chemical is released with each use
  - *Articles*: continual emission source of chemical
  - *Food*: can be included if data is available for amount of chemical in each food type
- Can produce exposure estimates for thousands of chemicals in a rapid and cost-effective manner

SHEDS-Multimedia (MM)

- Refined level model
- Uses 2-stage Monte Carlo process to separately estimate population variability and uncertainty
- Longitudinal model, time-series of exposure and intake dose is generated for each simulated person, usually covering 1 year.
- A time-series of exposure and intake dose is generated for each simulated person, usually covering one year.
- Can handle one chemical per run, or several related chemicals (such as household pesticides)

SHEDS Model Inputs

Inputs	Sources	SHEDS-HT	SHEDS-MM
Population Characteristics	• U.S. Census	X	X
	• NHANES – National Health and Nutrition Examination Survey		X
	• Physiology data from SHEDS-MM	X	
	• CHAD – Consolidated Human Activity Database	X	
Dietary Exposure Data	• NHANES – National Health and Nutrition Examination Survey	X	X
	• CSFII – Continuing Survey of Food Intake by Individuals		X
	• RAW – Raw Agricultural Commodity		X
	• FCID – Food Commodity Intake Database		X
	• PDP – Pesticide Data Program		X
	• TDS – Total Dietary Survey		X
Chemical Fate and Transport	• Fugacity modeling	X	X
	• EPI Suite – Estimation Program Interface		X
	• Values derived from EPI Suite	X	
	• Chemical properties from CompTox Dashboard	X	
Home Chemical Usage	• Home chemical usage database	X	X
Exposure and Dose Models	• ERDEM – Exposure Related Dose Estimating Models and other dose estimating models		X

EXAMPLES: Linking SHEDS with Other Models

- SHEDS is an exposure model; to evaluate risk, the results must be passed to another model
- SHEDS-MM (SHEDS-Multimedia) is a combination of two separate models: SHEDS-Residential and SHEDS-Dietary
- SHEDS-ERDEM (SHEDS-Exposure Related Dose Estimation Model): links SHEDS-MM to ERDEM, a physiologically-based pharmacokinetic (PBPK) and pharmacodynamic (PD) modeling system
- SHEDS-IEUBK: links SHEDS-MM to the Integrated Exposure Uptake Biokinetic (IEUBK) model for Pb to determine blood lead levels

EXAMPLE: Combined Models

- SHEDS is one of many linked models
- Discussion of models by Williams et al. (2010):
  - E-FAST (EPA OPPT): Screening-level estimates of chemicals released to air, water, landfills, from consumer products
  - TRIM (EPA OAQPS): “Next generation” model, estimates environmental concentrations, fate & transport, population-level exposures for ecological & human receptors
  - 3MRA (EPA ORD): Screening-level risk-based assessment of potential health risks from long-term exposure
- Many models are only used for research purposes
- Practical example: assessment of children’s exposure to CCA-treated wood in playsets by EPA OPP

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EXPOSURE RECONSTRUCTION FOR EXPOSURE ASSESSMENT

RATE

Risk Assessment Training & Experience

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Exposure Reconstruction for Exposure Assessment

- **Exposure reconstruction** uses pharmacokinetic (PK) models to estimate exposure from biomonitoring data (e.g., blood, urine)

- NHANES data include national biomonitoring data collected by CDC
  - Stratified by age, race, and sex for numerous chemicals

nhanes
The Nation's Mobile Health Survey

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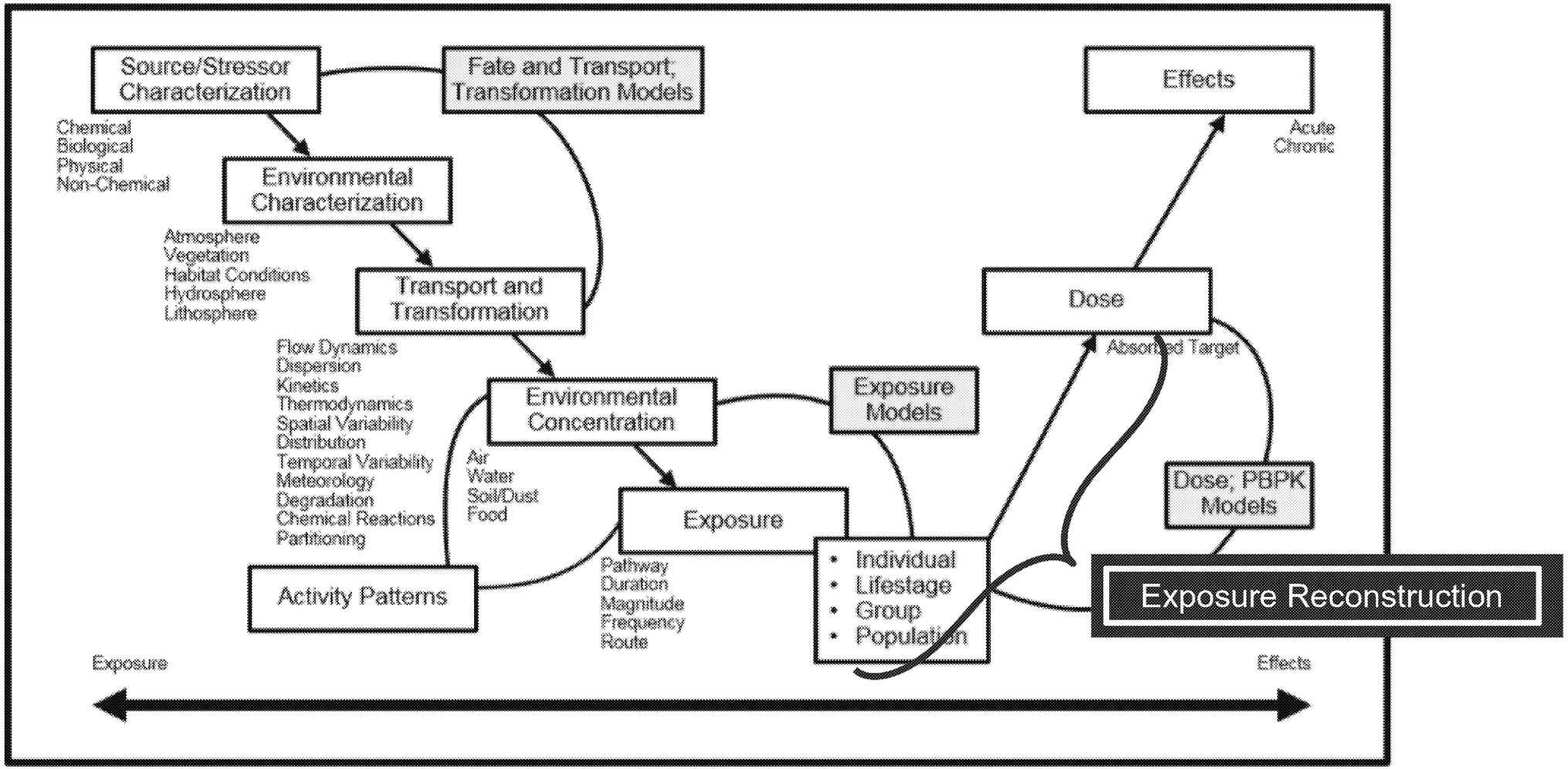
Where Does Exposure Reconstruction Fit?



Note: PBPK = physiologically based pharmacokinetic

Adapted from NRC (1983); NRC (1997)

Biomarkers for Exposure Reconstruction: Strengths and Weaknesses

Strengths:

- Provide confirmation of exposure to an agent
- Important for linking external exposure to internal dose and health outcomes
- One way to characterize total internal dose of agent from multiple sources (aggregate exposure)

Weaknesses:

- Not linked to pathway or source
- Requires pharmacokinetic (PK) model and parameters
- Sampling and evaluation may be expensive

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Exposure Reconstruction Example: Cadmium

Table 2
Geometric mean urinary cadmium concentrations (μg Cd/g of creatinine) found in the nonsmoking U.S. population by age from the National Health and Nutrition Examination Survey 2003–2004 (NHANES).

Age (years)	Males (95% confidence interval)	Females (95% confidence interval)
6–11	0.088 (0.071–0.11)	0.088 (0.072–0.108)
12–19	0.074 (0.066–0.083)	0.103 (0.089–0.118)
20–39	0.125 (0.114–0.137)	0.179 (0.159–0.202)
40–59	0.208 (0.184–0.234)	0.342 (0.305–0.383)
60+	0.366 (0.324–0.414)	0.507 (0.46–0.558)

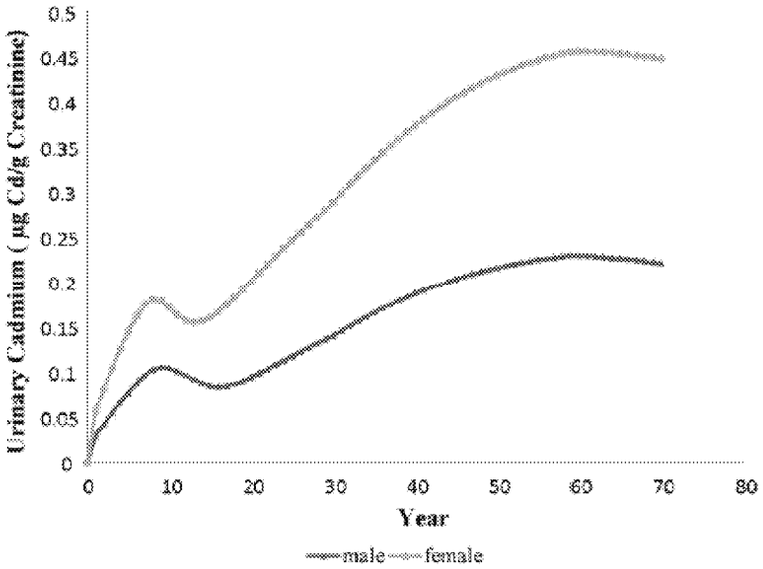

Fig. 1. Model predictions of urinary cadmium excretion in the U.S. population (males and females). The upper model simulation shows the female cadmium urinary excretion and the lower shows the male cadmium urinary excretion.

Table 3
Dietary cadmium intake and model predictions of urinary cadmium in the nonsmoking U.S. population (corrected for creatinine) (μg Cd/g creatinine).

Age (years)	Males		Females	
	Cd intake U.S. (GM)[a] (μg Cd/day)	Model predictions	Cd intake U.S. (GM)[a] (μg Cd/day)	Model predictions
6–11	15.0	0.101 (0.088–0.11)	13.5	0.172 (0.152–0.188)
12–19	19.7	0.087 (0.078–0.095)	15.1	0.163 (0.136–0.190)
20–39	22.4	0.137 (0.082–0.190)	16.2	0.285 (0.182–0.386)
40–59	22.1	0.214 (0.188–0.241)	16.5	0.427 (0.377–0.477)
60+	17.6	0.226 (0.221–0.232)	14.4	0.453 (0.447–0.459)

GM: geometric mean.
[a] From Choudhury et al. (2001).

Ruiz, et al. 2010. Interpreting NHANES biomonitoring data, cadmium. Toxicology Letters 198. 44-48.

Exposure Reconstruction Example: PFOS

Table 3. Summary of studies measuring general population blood concentrations of five key PFCs measured in the United States (all units = ng/ml; M = male; F = female).

Study description	PFOS	PFOA	PFOSA	PFNA	PFHS
Calafat et al. (2007); $n = 2094$, NHANES 2003/2004; serum, GM (% detected)	M: 23.6 F: 18.5	M: 4.5 F: 3.5	0.2 (22%)	M: 1.1 F: 0.9	M: 2.2 F: 1.7
Calafat et al. (2007); $n = 1562$, NHANES 1999/2000; serum, median	M: 33.4 F: 28.0	M: 5.7 F: 4.8	M: 0.4 F: 0.2	M: 0.6 F: 0.5	M: 2.7 F: 1.7

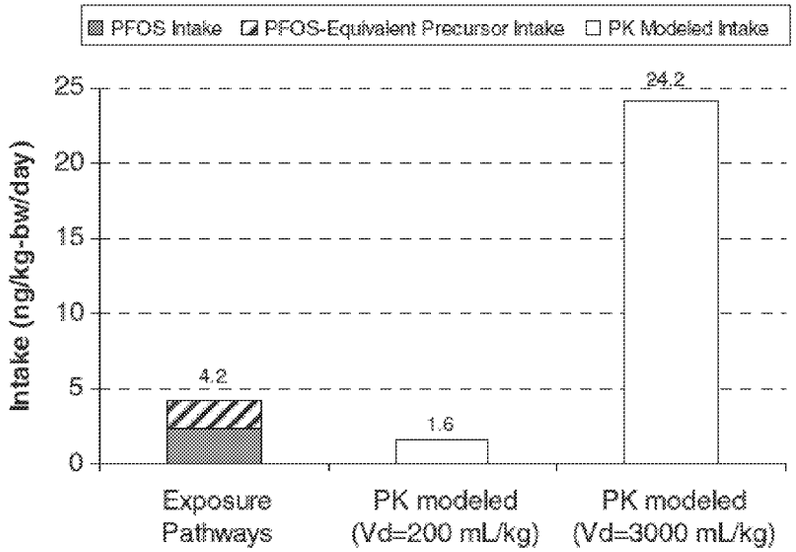

Figure 4. Median intake of PFOS by adults based on an exposure pathway analysis compared with intakes predicted using the PK model, separately assuming volume of distribution (*Vd*) of 200 and 3000 ml/kg.

Egeghy P. and Lorber, M. 2011. An assessment of the exposure of Americans to perfluorooctane sulfonate: a comparison of estimated intake with values inferred from NHANES data. Journal of exposure science & environmental epidemiology, 21(2), 150-168

United States Environmental Protection Agency

CONCLUSION

RATE

Risk Assessment Training & Experience

Summary

- Quantify exposures to stressors and potential impacts on receptor populations
- Depends on data, resources, exposure of concern, stressors, and receptor populations
- Tiered approach helps to guide, refine, and select appropriate methods
  - Deterministic versus probabilistic
- Quantification approaches all have strengths and weaknesses, one or multiple might be best, depending on the scenario
  - Point-of-contact
  - Scenario evaluation
  - Exposure reconstruction

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Program Specific Commonly Used Resources

- Regional Screening Levels (RSLs)
  - Superfund screening levels that help identify areas at a site, contaminants, and conditions that require further federal attention.
  - RSLs User's Guide – Guidance on risk assessment approach
  - RSL Calculator - Calculator for decision-makers at hazardous waste sites to determine whether levels of contamination found at the site may warrant further investigation or consideration for site cleanup, or whether no further investigation or action may be required for specific chemicals. RSLs are used to identify Chemicals of Potential Concern to include in the Baseline Human Health Risk Assessment.
  - RSLs Generic Tables – Provides generic chemical-specific concentrations for individual contaminants in various media
  - Lead at Superfund Sites – Lead models
- Information for Assessing Risks to Children

Additional Resources

- EPA ExpoBox Unit Conversions Table

- Exposure Estimate Calculators (commonly used EPA tools)
  - ExpoFirst, APEX, ChemSTEER, CEM, E-FAST, SHEDS, TRIM.FaTE, 3MRA, SOPs for Residential Pesticide Exposure Assessment

- USGS Background Soil-Lead Levels

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Exposure Quantification Approaches at a Glance

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

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