# Case Study Applications of Human Exposure Models

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U.S. Environmental Protection Agency

# Contributors

**Case Study 1**

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**Case-Study 2 and 3**

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# Outline

- Definition of Exposure Models
- Illustrative Examples
  - Case-Study 1: Modeling Exposures to $PM_{2.5}$ in Philadelphia, USA
  - Case-Study 2: Assessing Children's Exposure to Pesticides
  - Case-Study 3: Modeling Dietary Exposures to Pesticides
- Lessons Learned and Modeling Challenges

# Exposure Models

- Exposure models are structured mathematical representations used for predicting real-world exposure events by linking measurements or modeling information on:
  - Emissions
  - Concentrations
  - Behavioral information
  - Exposure factors
  - Other exposure related data

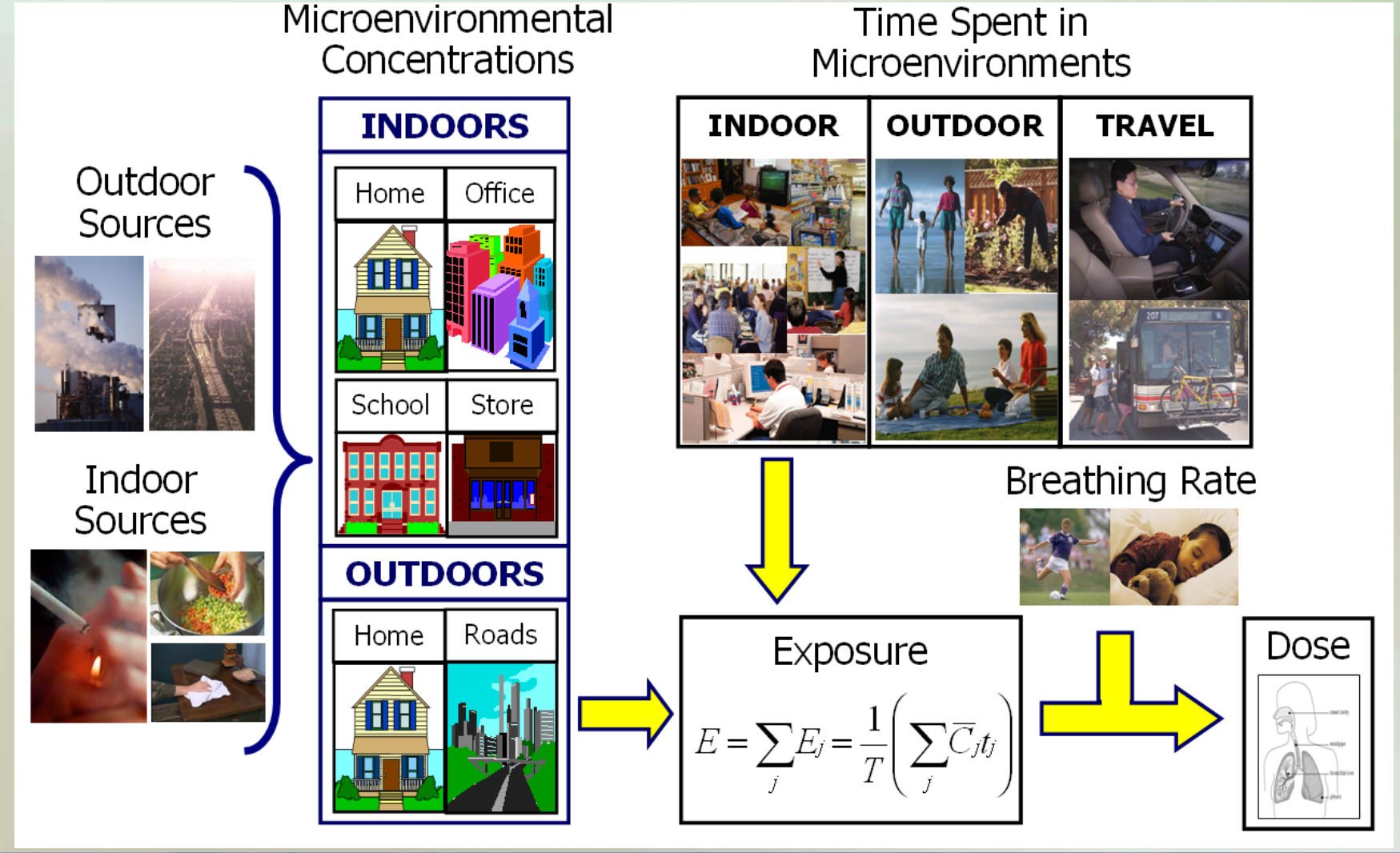
# Case-Study 1: Modeling Exposures to $PM_{2.5}$ in Philadelphia

## Objectives

- Understand key pathways and behavioral factors influencing population exposures to ambient and non-ambient $PM_{2.5}$ using the EPA SHEDS-PM 3.5 model (in MATLAB®)*
- Estimate indoor concentrations of $PM_{2.5}$ as a function of building parameters, particle deposition, indoor source strengths, air exchange rate
- Quantify variability in modeled exposures (for an individual vs. population subgroups) based on a simulation of 215 individuals living in one of the census tracts in Philadelphia, PA
- Compare predicted variability to parameter uncertainty produced for the entire Philadelphia area

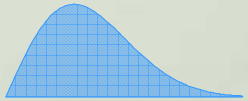
*Contact Dr. Janet Burke at EPA (burke.janet@epa.gov) for information on accessing model code and accompanying documentation

# Stochastic Human Exposure and Dose Simulation Model for PM (SHEDS-PM)



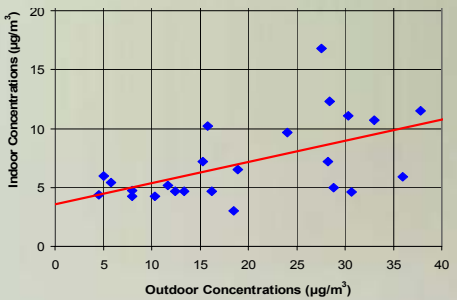
# Exposure Pathways: Inhalation

- Microenvironmental concentrations
  - Concentration distribution



  - Indoor/outdoor ratio

$$f(x)$$

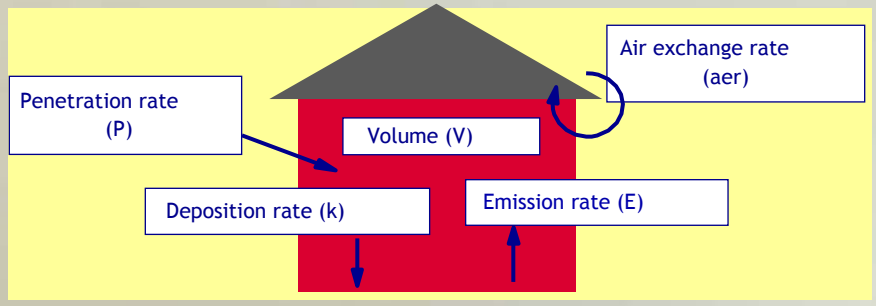



  - Indoor/outdoor regression equation
  - Mass balance equation:

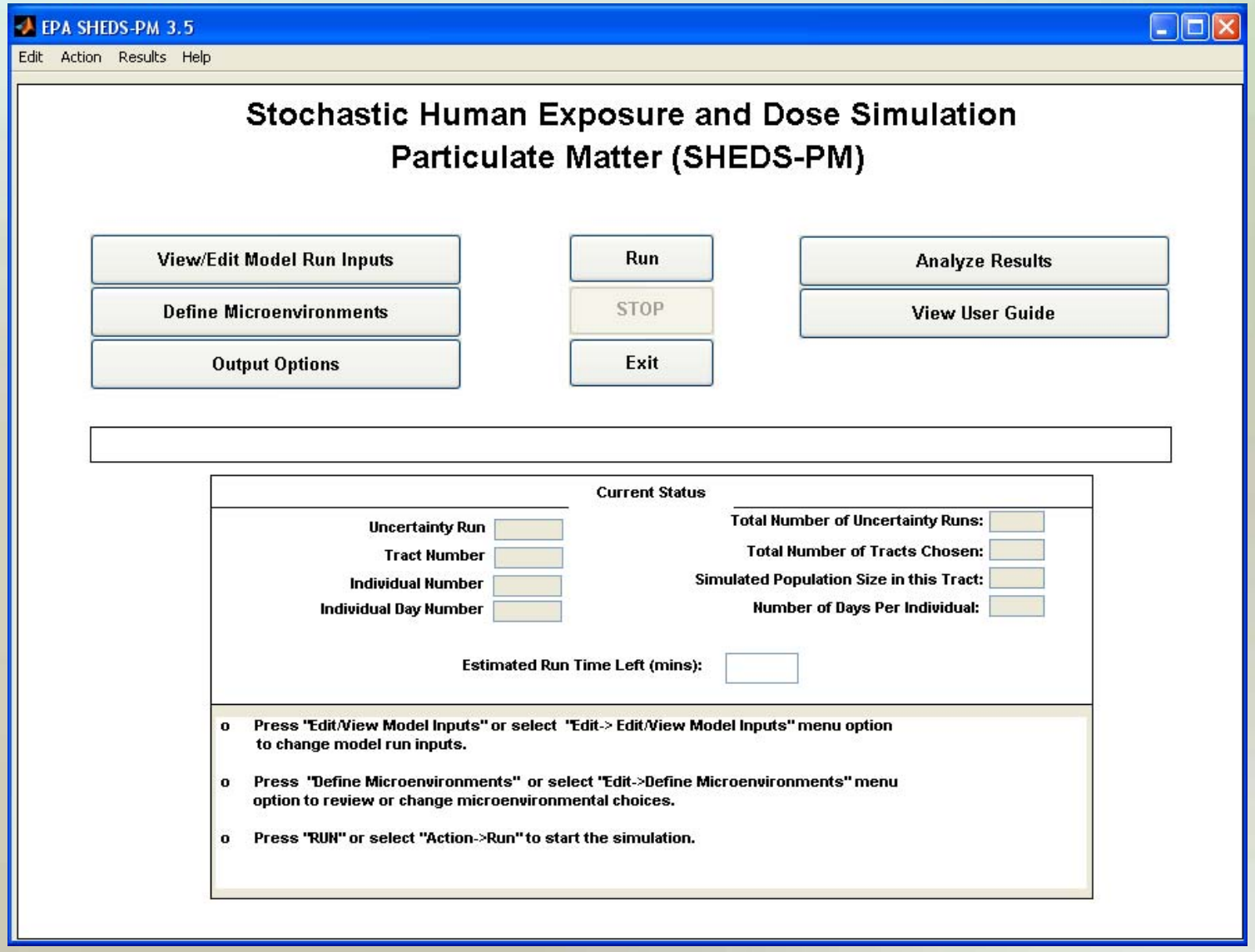
$$C_{in} = \left(C_{out}\frac{P^{*}aer}{aer+k}\right) + \frac{E_{smoke}{*}N_{cig} + E_{cook}{*}t_{cook} + t_{other}{*}E_{other}}{(aer+k){*}V{*}T}$$

*{assuming uniform mixing and steady state}*

$$F_{inf} = \frac{P * aer}{(aer+k)}$$



# Main SHEDS-PM User Interface Screen



# Mass-Balance Model Parameter Distributions for the Case-Study Homes

μ = Arithmetic mean

σ = Arithmetic standard deviation (std.dev.)

$x_g$= Geometric mean (also median for a lognormal)

$\sigma_g$= Geometric standard deviation (gsd)

Normal ≡ N (μ, σ)

Lognormal ≡ Ln N ($x_g$, $\sigma_g$)

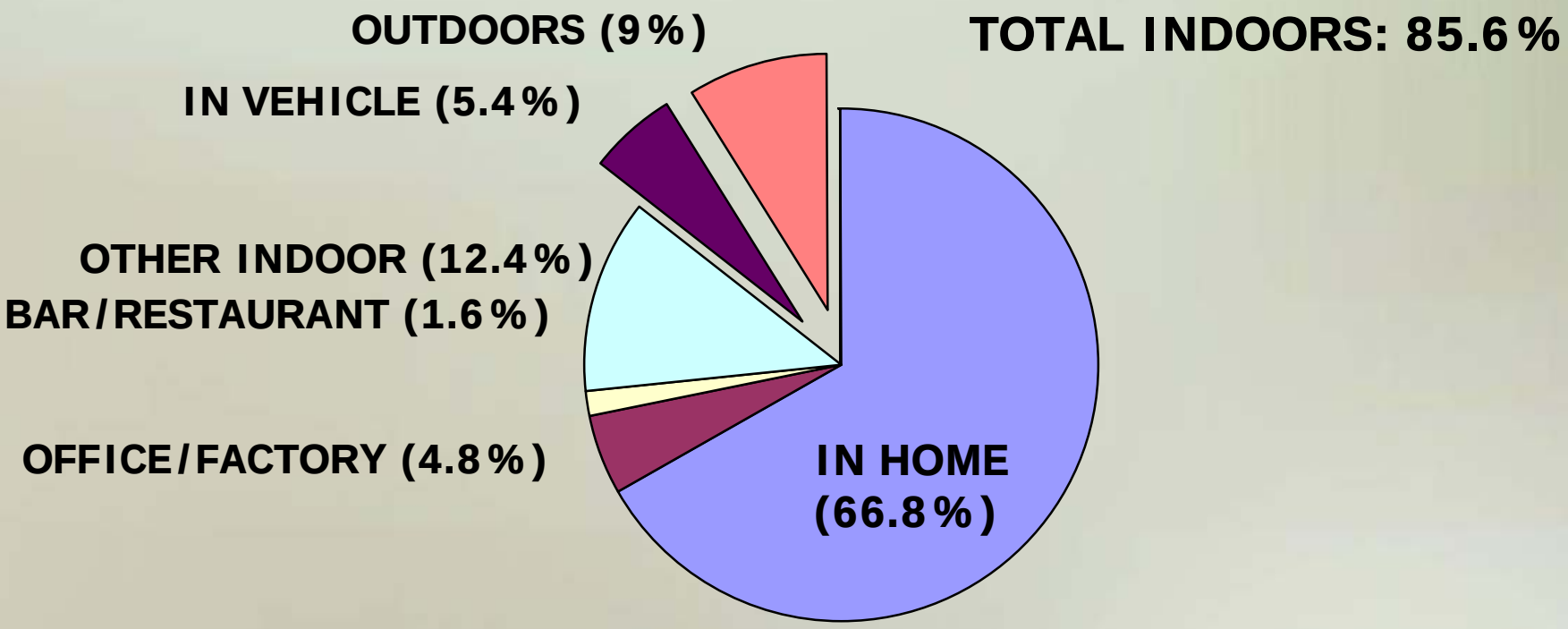
- Air exchange rate (aer): Ln N (0.82, 2)
- Deposition rate (k): N (0.3, 0.1)
- Penetration coefficient (P) : N (0.97, 0.02)
- Volume (V): Ln N (412, 1.6) {single family detached}
- Cooking Emissions ($E_{cook}$) : N (1.56, 0.412)

# Relationships between Ambient and Indoor Microenvironments for PM

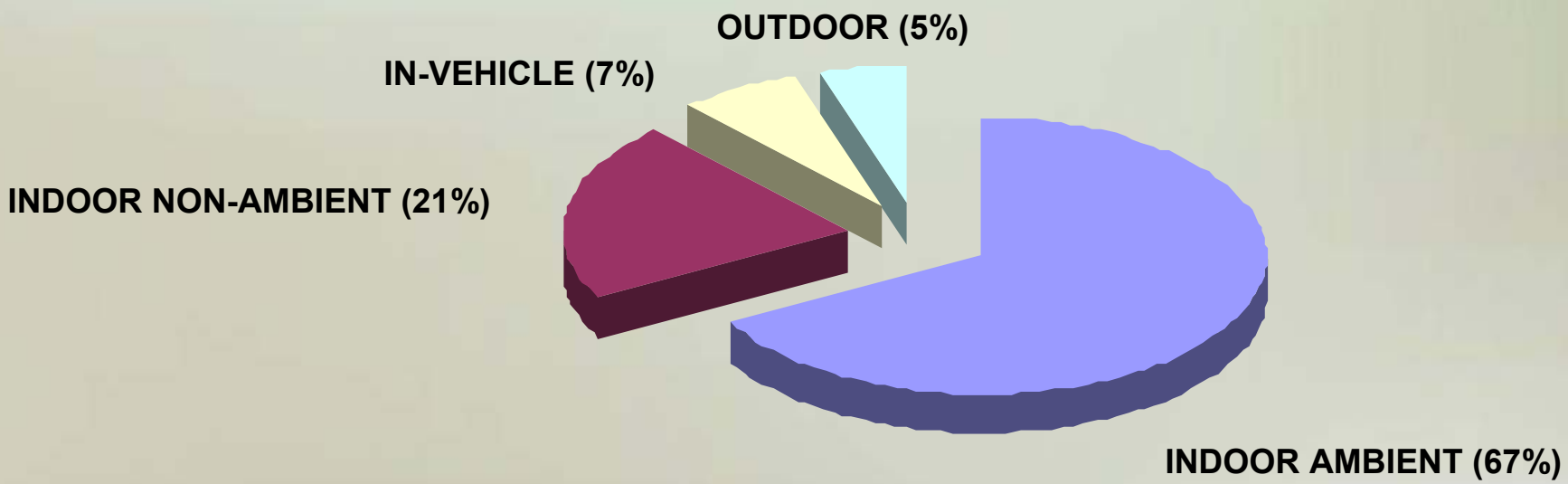
## (Indoor PM=$\beta_0$+ $\beta_1$Ambient PM +Residual Error)

| Microenvironment Type | Slope | Intercept | Residual Mean | Residual Std. Deviation |
|---|---|---|---|---|
| Office | 0.18 | 3.6 | 0 | 2.9 |
| School | 0.6 | 6.8 | 0 | 5.4 |
| Store | 0.75 | 9.0 | 0 | 2.1 |
| Restaurant | 1.0 | 9.8 | 0 | 10.0 |
| Bar | 1.0 | 9.8 | 0 | 10.0 |
| In-Vehicle | 0.71 | 0 | 0 | 6.64 |
| All Other | 0.85 | 8.4 | 0 | 4.0 |

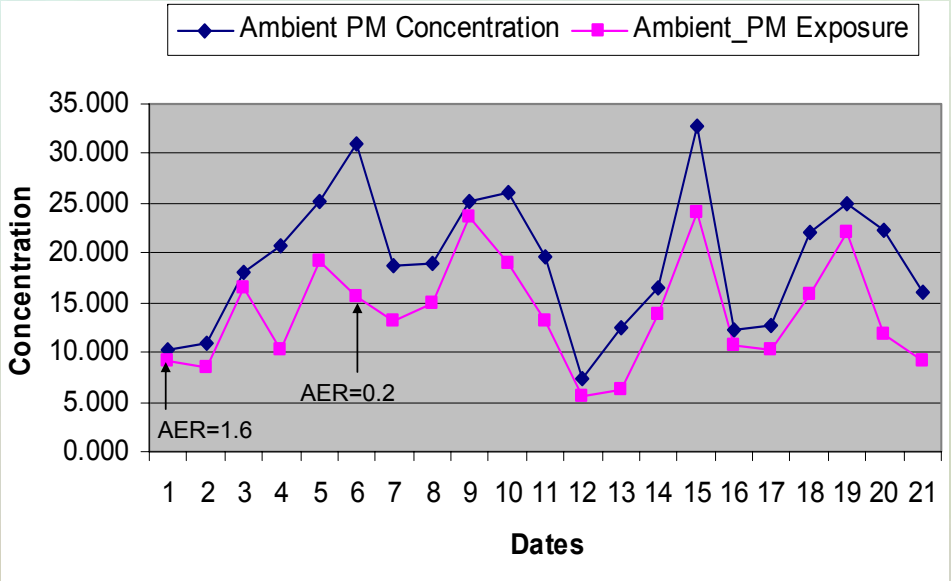
# Average Percent Time Spent in Each Microenvironment: Philadelphia Case Study

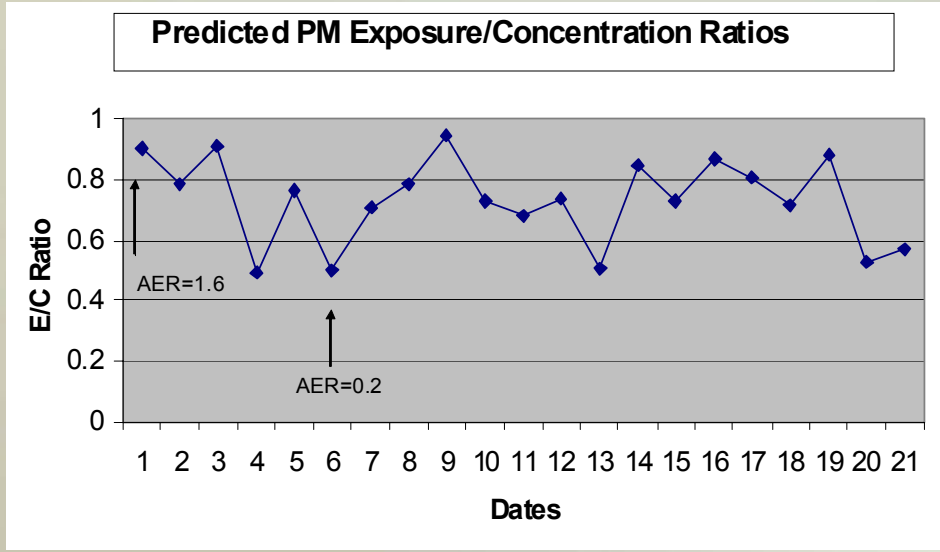


# Predicted PM Exposures by Ambient and Non-Ambient Sources: Philadelphia Case Study

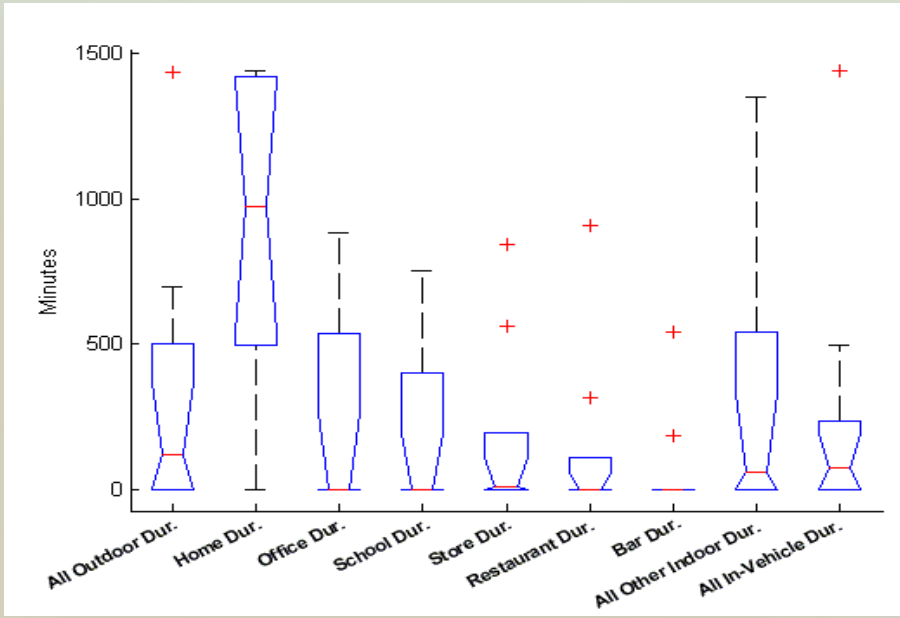


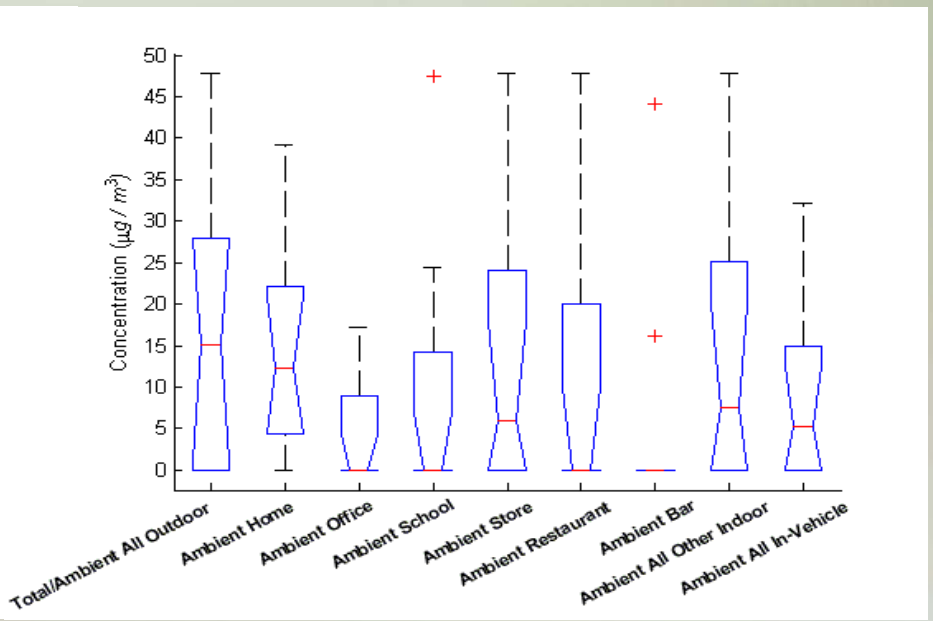
# SHEDS-PM Example for a Case-Study Subject



# Box Plots of Time Spent and PM Concentrations in Different Microenvironments



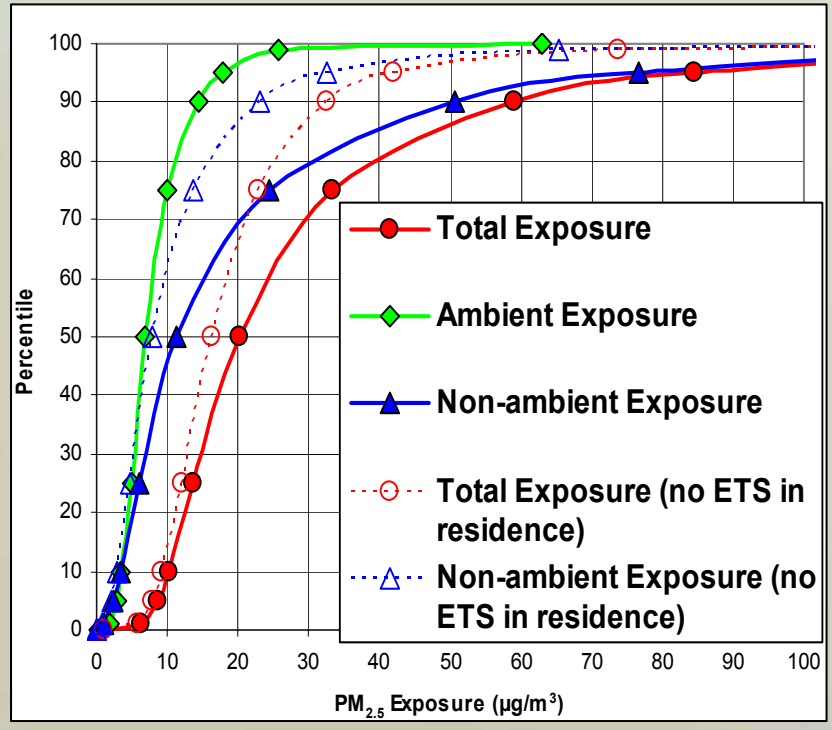



# Variability vs. Uncertainty: SHEDS- PM Results for Entire Philadelphia

## Ambient $PM_{2.5}$ Exposure

Median = 7 µg/m³

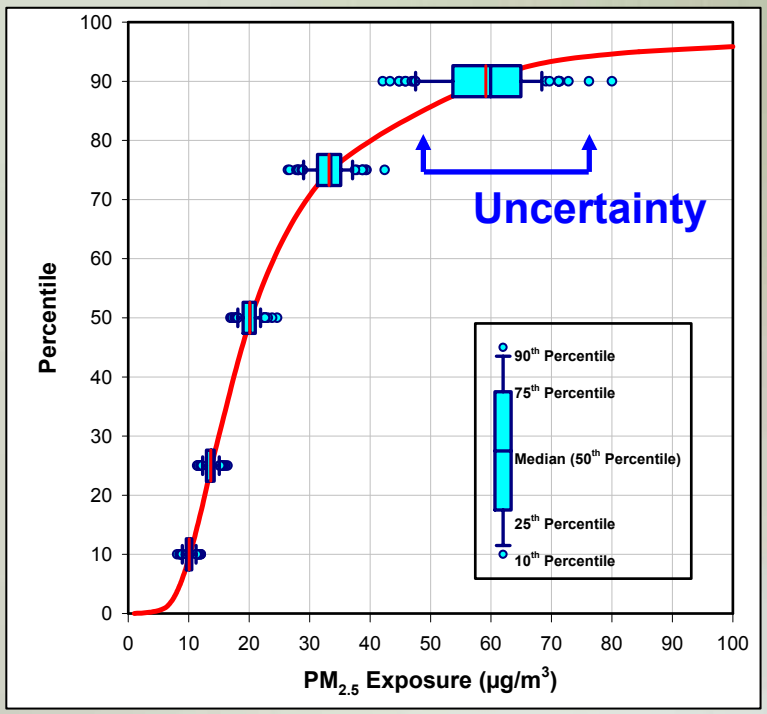
95th %tile = 18 µg/m³




## Total $PM_{2.5}$ Exposure

Median = 20 µg/m³

95th %tile = 84 µg/m³




**Source: Burke et al., 2001**

# Case-Study 2: Assessing Children's Exposure to Pesticides

## Objectives

- Understand key multimedia exposure pathways, behavioral factors, application types and patterns influencing exposures of children to residential use pesticides using the SHEDS-Multimedia model (version 3) (in SAS®)*
- Describe lower vs. higher tier exposure modeling methods
- Quantify variability and uncertainty in modeled hypothetical pesticides exposure and dose for children
- Compare SHEDS results to other probabilistic pesticide exposure models and lower-tier default EPA SOPs

*SHEDS-Multimedia Model (version 3) can be accessed through:
http://www.epa.gov/heasd/products/sheds_multimedia/sheds_mm.html
Contact Dr. Valerie Zartarian at EPA (zartarian.valerie@epa.gov) for technical questions

# Assessing Exposures and Risks to Pesticides

Four principal categories for assessing risks:

- Food
- Aggregate
  - Food
  - Drinking water
  - Residential
- Cumulative
- Occupational

Exposure averaging periods of interest:

- Acute
- Short-term
- Intermediate Term
- Chronic
- Lifetime

# Multimedia Exposure Pathways for Children



# Modeling Exposures to Pesticides

## Lower Tier

**(Hand-to-Mouth)**

**HTM: Exposure Equation and Calculation**

***ADD*** *= Average daily dose (mg/kg/day)*

$$\mathbf{ADD = \frac{(DR * SA * FQ * SE * ET)}{BW}}$$

*Where:*

***DR*** *= Dislodgeable Residue (mg/cm$^2$)*

***SA*** *= Surface area of fingers (20 cm$^2$/event)*

***FQ*** *= Frequency of activity (20/hr)*

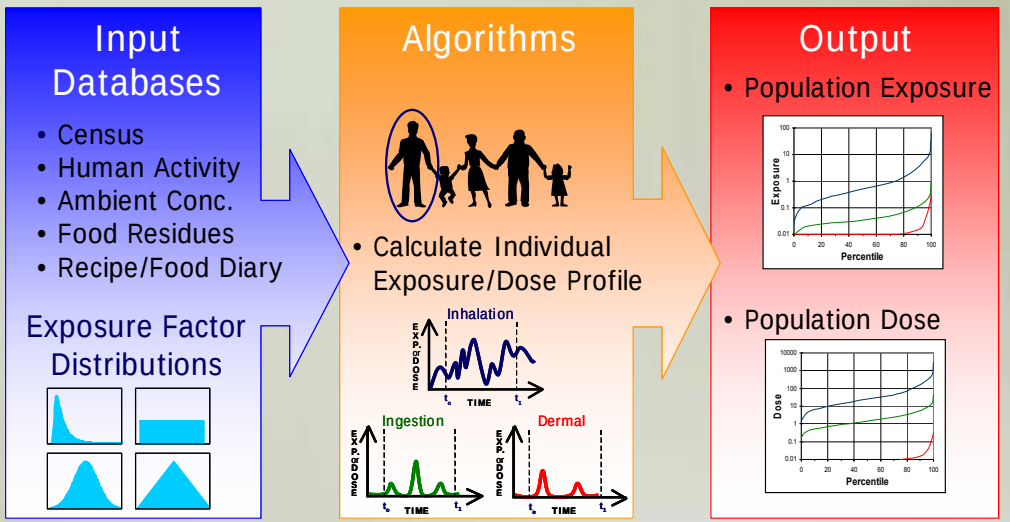
***SE*** *= Saliva Extraction factor (50%)*

***ET*** *= Exposure Time (2 hr)*

***BW*** *= Body Weight (15 kg)*

Source: EPA/OPP

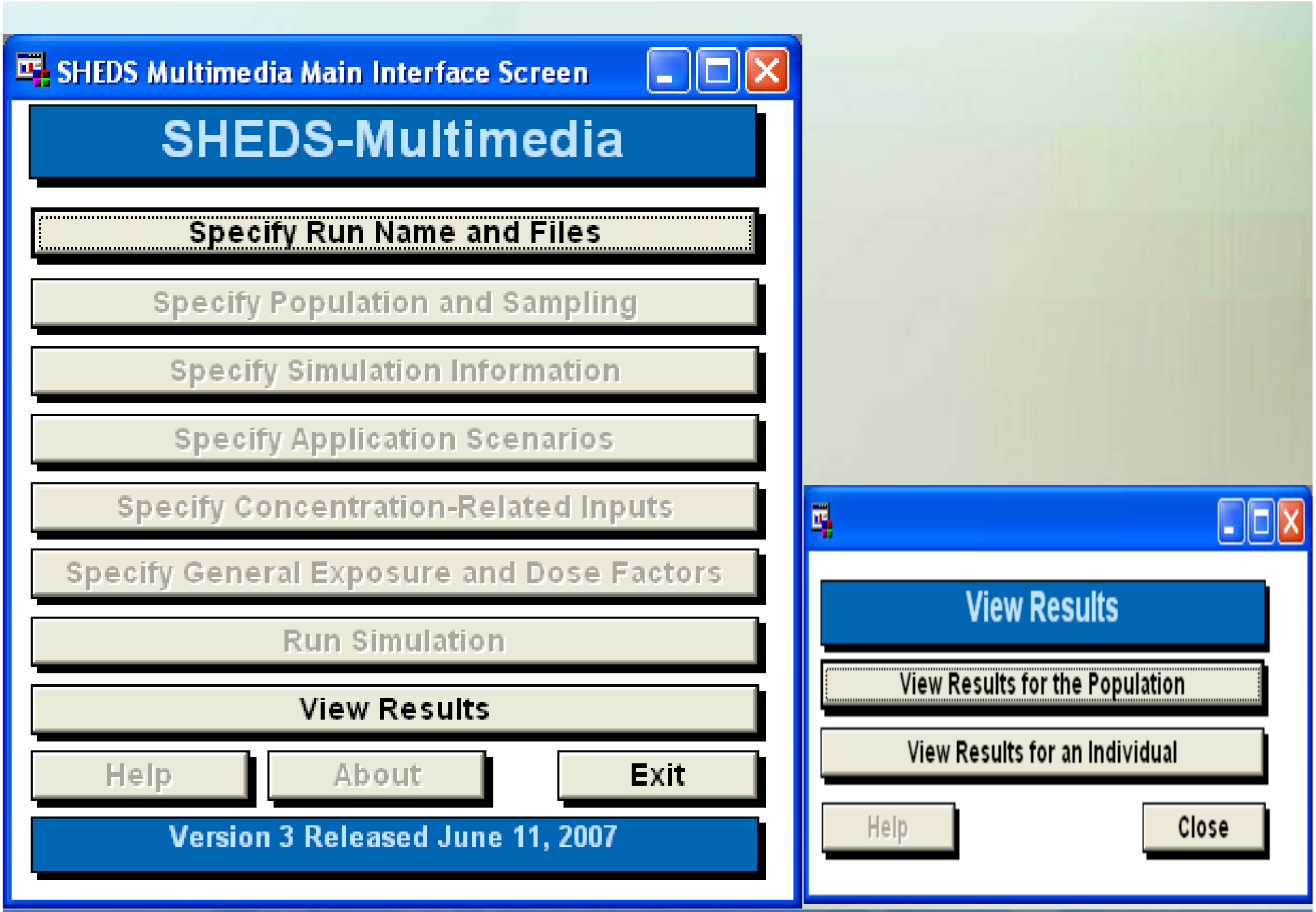
## Higher Tier




Source: EPA/ORD/NERL

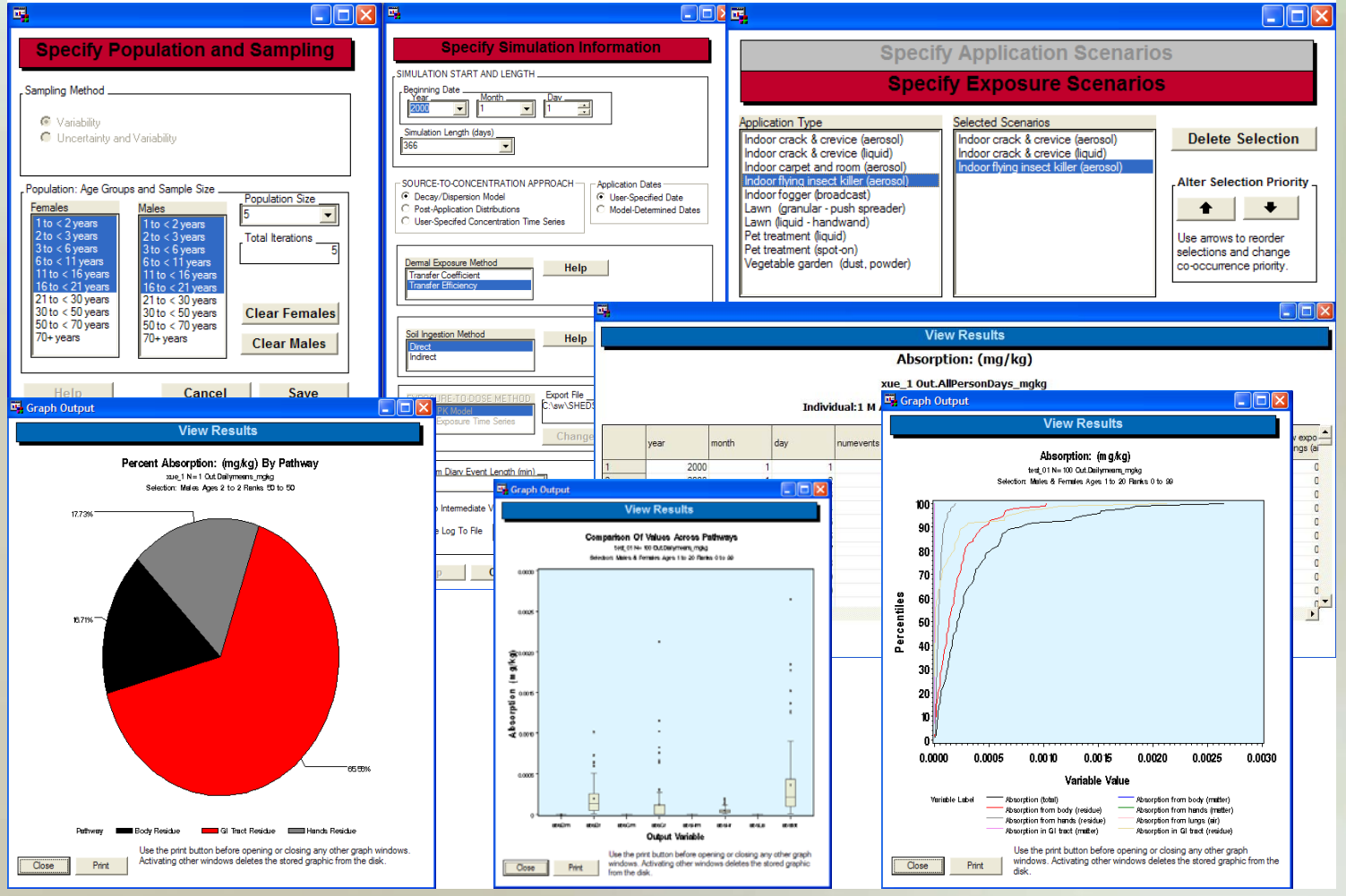
# Stochastic Human Exposure and Dose Simulation Model for Multimedia Pollutants (SHEDS-Multimedia)

- SHEDS-Multimedia is a state-of-science probabilistic model for producing estimates of human exposure and dose to multimedia, multipathway pollutants
- Questions SHEDS-Multimedia can help answer:
  - What is the population distribution of exposure (variability/uncertainty)?
  - What is intensity, duration, frequency, route, timing of exposures?
  - How do we effectively reduce the exposure (media, pathways, factors)?
  - How do we address greatest uncertainty/greatest risk?
  - Can we verify exposure estimates with available biomarkers?

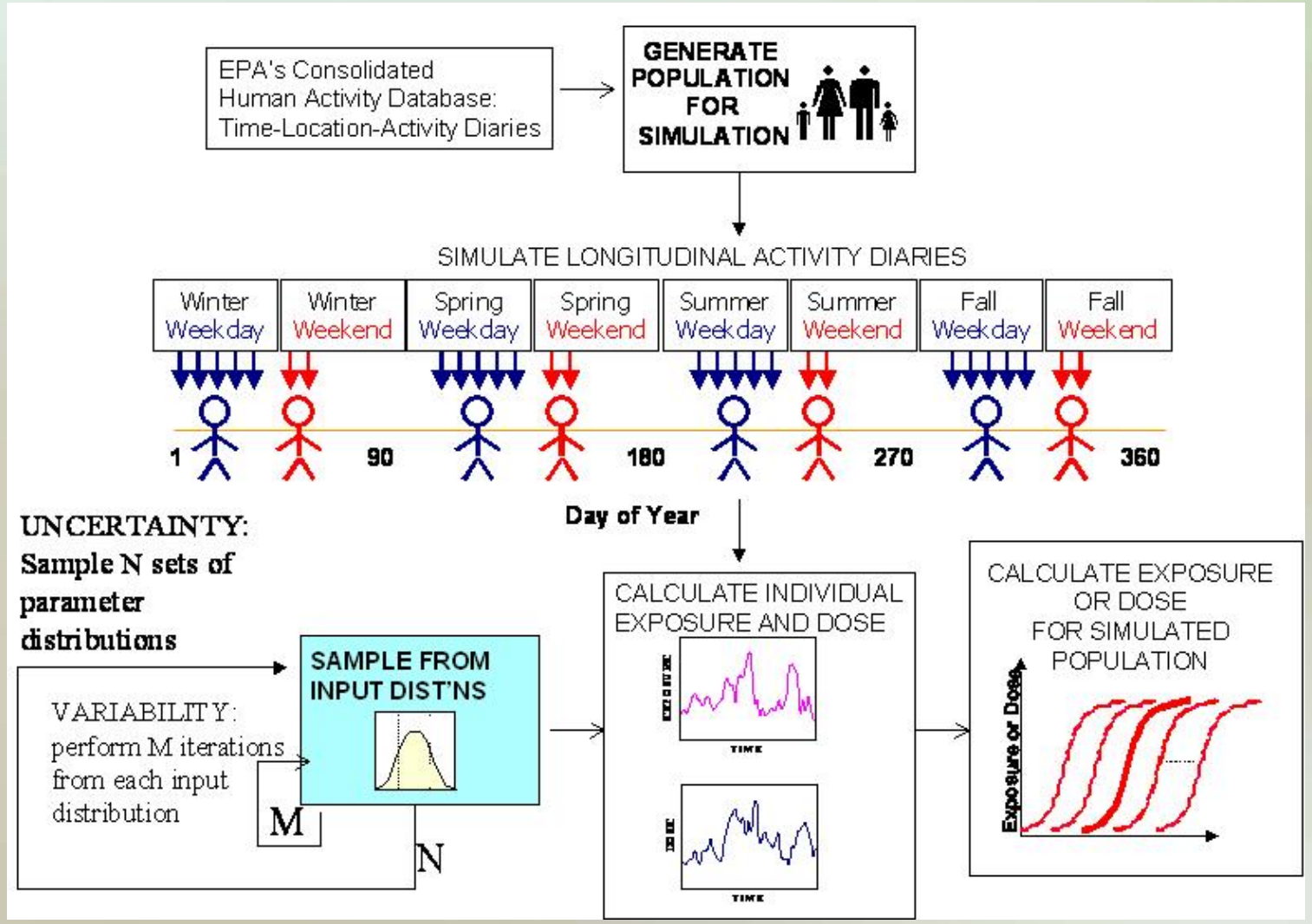

SHEDS Multimedia Main Interface Screen
SHEDS-Multimedia
Specify Run Name and Files
Specify Population and Sampling
Specify Simulation Information
Specify Application Scenarios
Specify Concentration-Related Inputs
Specify General Exposure and Dose Factors
Run Simulation
View Results
Help
About
Exit
Version 3 Released June 11, 2007
View Results
View Results for the Population
View Results for an Individual
Help
Close

# SHEDS-Multimedia (Version 3)

## User-Friendly GUI



# SHEDS-Multimedia Model Structure



# Model Inputs

- **Types**
  - simulated population
  - chemical usage-related
  - contact probability-related
  - concentration/residue-related
  - exposure and dose factors
- **Features**
  - 3 types stochastic sampling
  - SHEDS input distribution types
  - sampling frequency
  - SHEDS permits randomly sampled variables to be correlated

# SHEDS-Multimedia Outputs

- Simulated Individuals' Outputs for Various Exposure and Dose Metrics
  - raw data, exposure calculations, exposure time profiles
  - for code verification and examination of extremes
- Population Outputs for Various Exposure and Dose Metrics (variability and uncertainty)
  - summary statistics tables, box plots, cdfs
  - contribution by routes, pathways (pie charts, tables)
- Sensitivity Analyses
  - ranked input table: percentile scaling and multiple stepwise regression
- Uncertainty Analyses (input distributions via bootstrap approach)
  - ranked input table: Spearman, Pearson correlation, stepwise regression
  - 2 types of graphs
    - 3 variability dist'n CDFs ($5^{th}$, $50^{th}$, $95^{th}$ %iles by uncertainty run medians)
    - $5^{th}$, $50^{th}$, $95^{th}$ %iles from each of uncertainty runs

# Overview of SHEDS-Multimedia v.3 (aggregate residential) methodology

1) Read in exposure scenario and simulation information
2) Create a simulated individual
3) Generate individual's longitudinal activity pattern
4) Simulate contact events
5) Set days and times of chemical applications (if applicable)
6) Generate concentration time series for the contact media
7) Generate exposure time series for individual
8) Generate dose time series for the individual (if applicable)
9) Extract daily statistics from exposure or dose time series
10) Generate population variability estimates

*Conduct sensitivity and uncertainty analyses*

# 1) Read in exposure scenario and simulation information

- Genders
- Ages
- Sample size
- Dates of simulation
- Source-concentration approach
- Dermal exposure method
- Soil ingestion method
- Exposure-to-dose method
- Application scenarios

# 2) Create a simulated individual

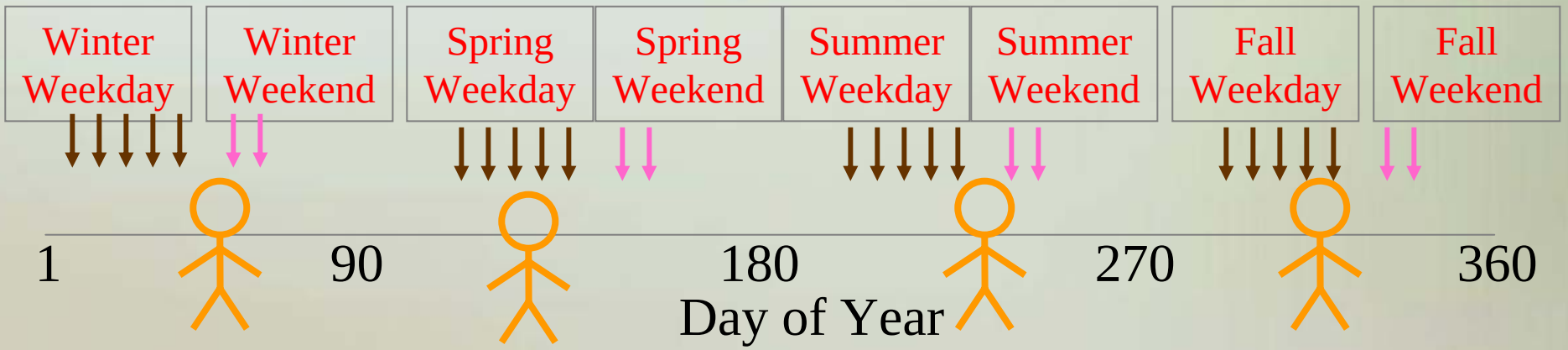
- Assign age, gender to individuals using US Census weights

**Example**

| Age | Females | Males |
|---|---|---|
| 2 yr | 0.160312 | 0.167891 |
| 3 yr | 0.162219 | 0.169628 |
| 4 yr | 0.165864 | 0.174087 |

- Assign or calculate other person-level variables
  - physiological, housing-related, behavioral

# 3) Generate longitudinal activity pattern for simulated individual



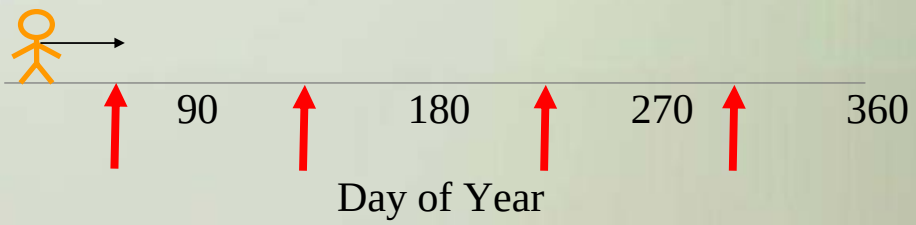

- 8 CHAD* diaries simulate a person's year in specified age-gender cohort
- Age-gender cohorts: 1 to <2 yr, 2 to <3 yr, 3 to <6 yr, 6 to <11 yr, 11 to <16 yr, 16 to <21 yr, 21 to <30 yr, 30 to <50 yr, 50 to <70 yr, 70+ yr

* http://www.epa.gov/chadnet1; McCurdy et al., 2000

# 4) Simulate contact events with relevant media

- Assign microenvironment and medium for each diary event
- 5 microenvironments mapped from CHAD
  - in home, in vehicle, in other bldg, outside home, outside away
- Contact media within microenvironments
  - air, smooth surfaces, textured surfaces, lawn, garden, pet
- Chemical carriers for contact media
  - air, residues, dust/soil ("matter")

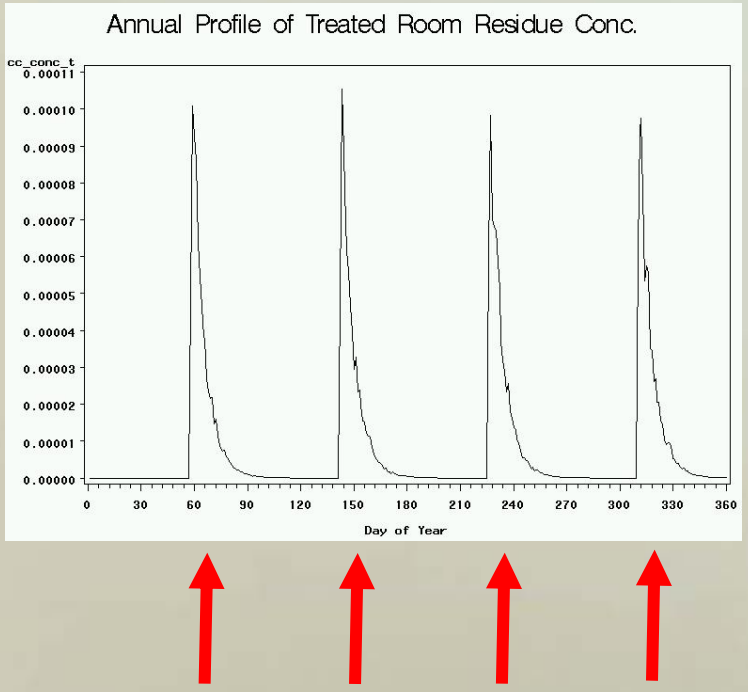
# 5) Set chemical application times (if applicable)




- 10 possible chemical application types in SHEDS v.3
- 'User Dates' option
- user specifies days w/ usage, for each application type
- 'Model Dates' option
- model randomly selects usage dates for each app. type, person

# 6) Set conc. time series for contact media

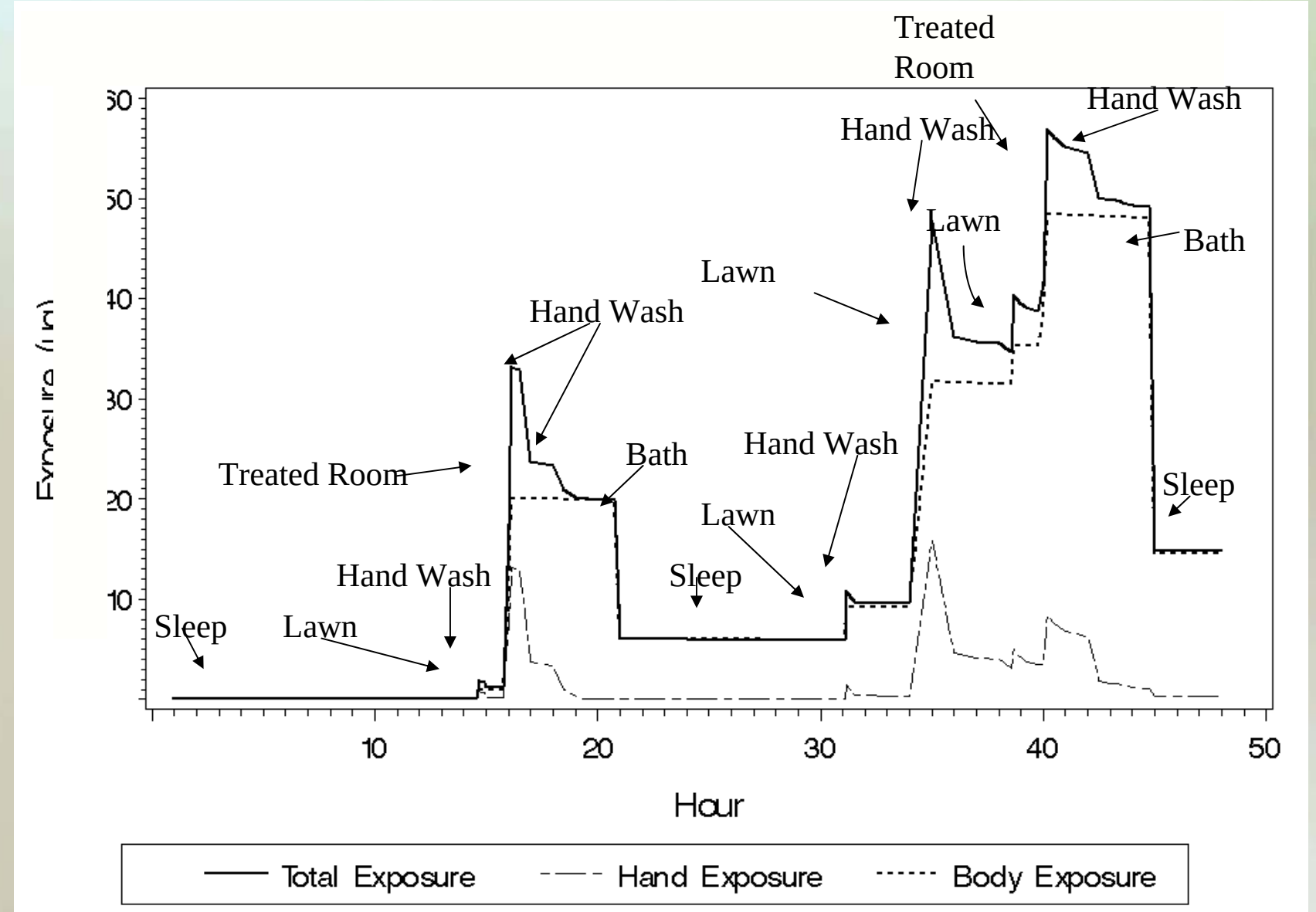
- Decay-dispersion method
- Post-application method
- User-specified time series method



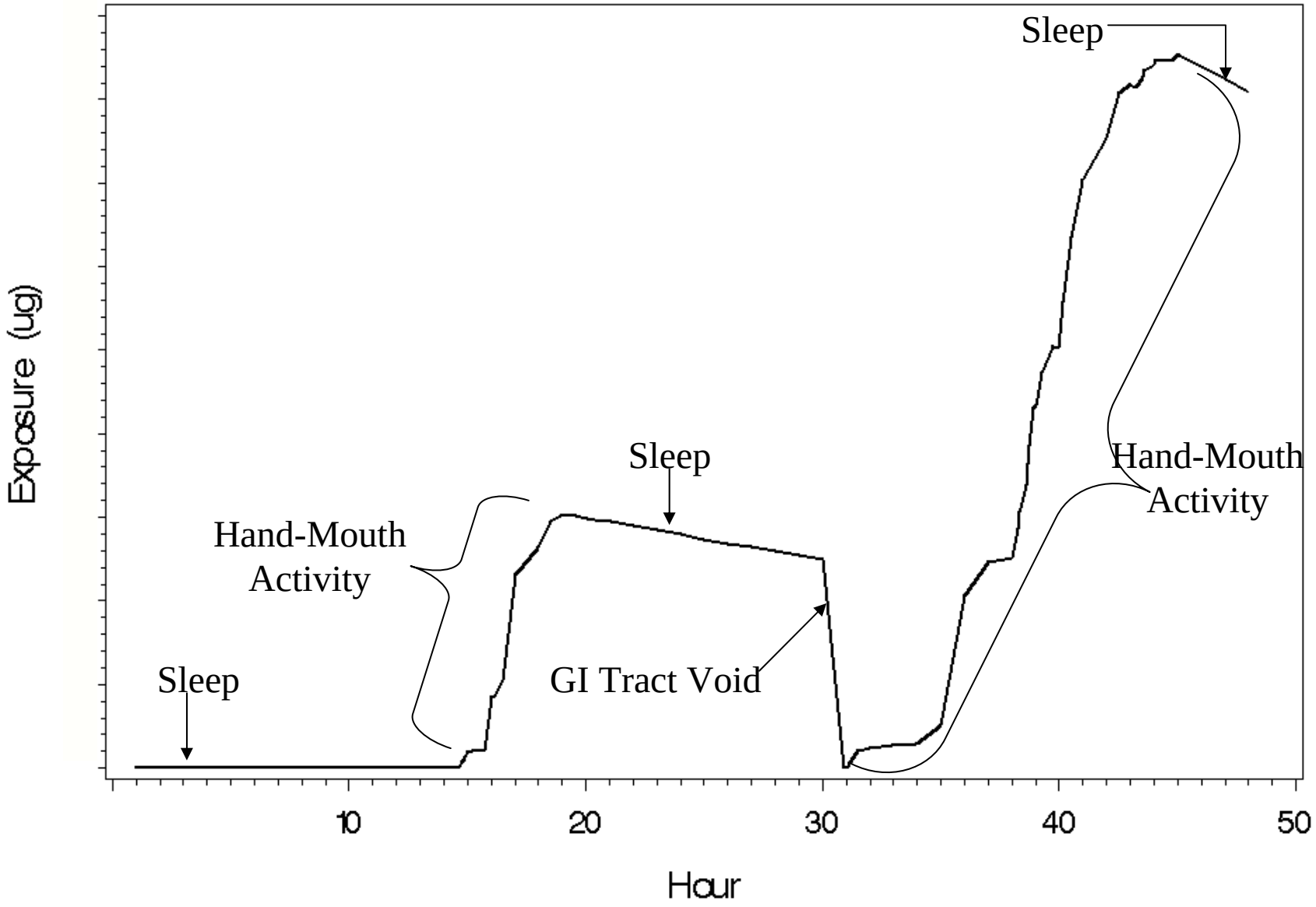

# 7) Generate exposure time series

- "New exposure" equations by pathway
- dermal:
  - surface residues to hands and body
  - dust/soil to hands and body
- non-dietary ingestion:
  - hand residues to GI tract
  - object residues to GI tract
  - dust/soil to GI tract
- inhalation: air to lungs

# Hypothetical Dermal Exposure Time Series

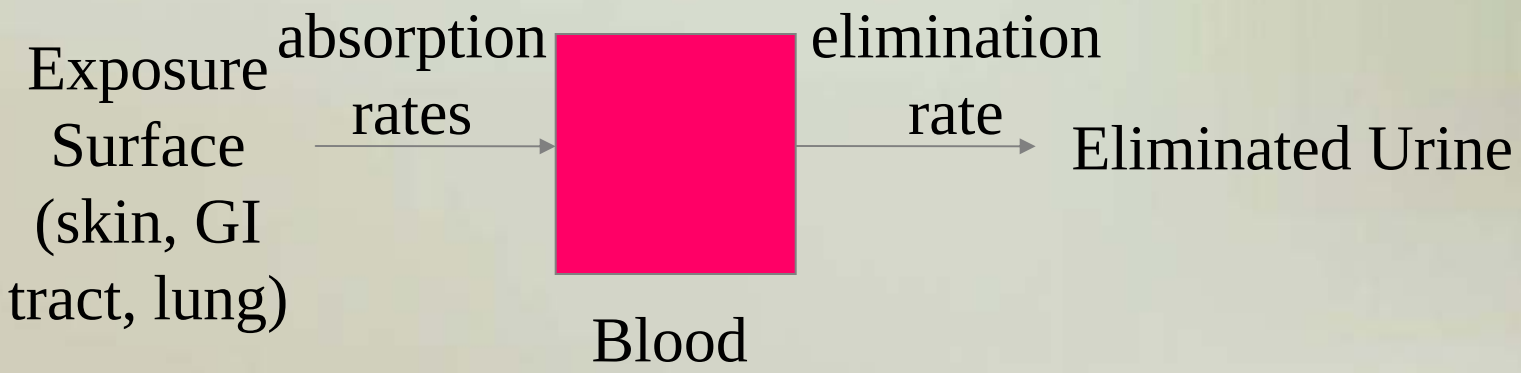


# Hypothetical Non-Dietary Ingestion Exposure Time Series

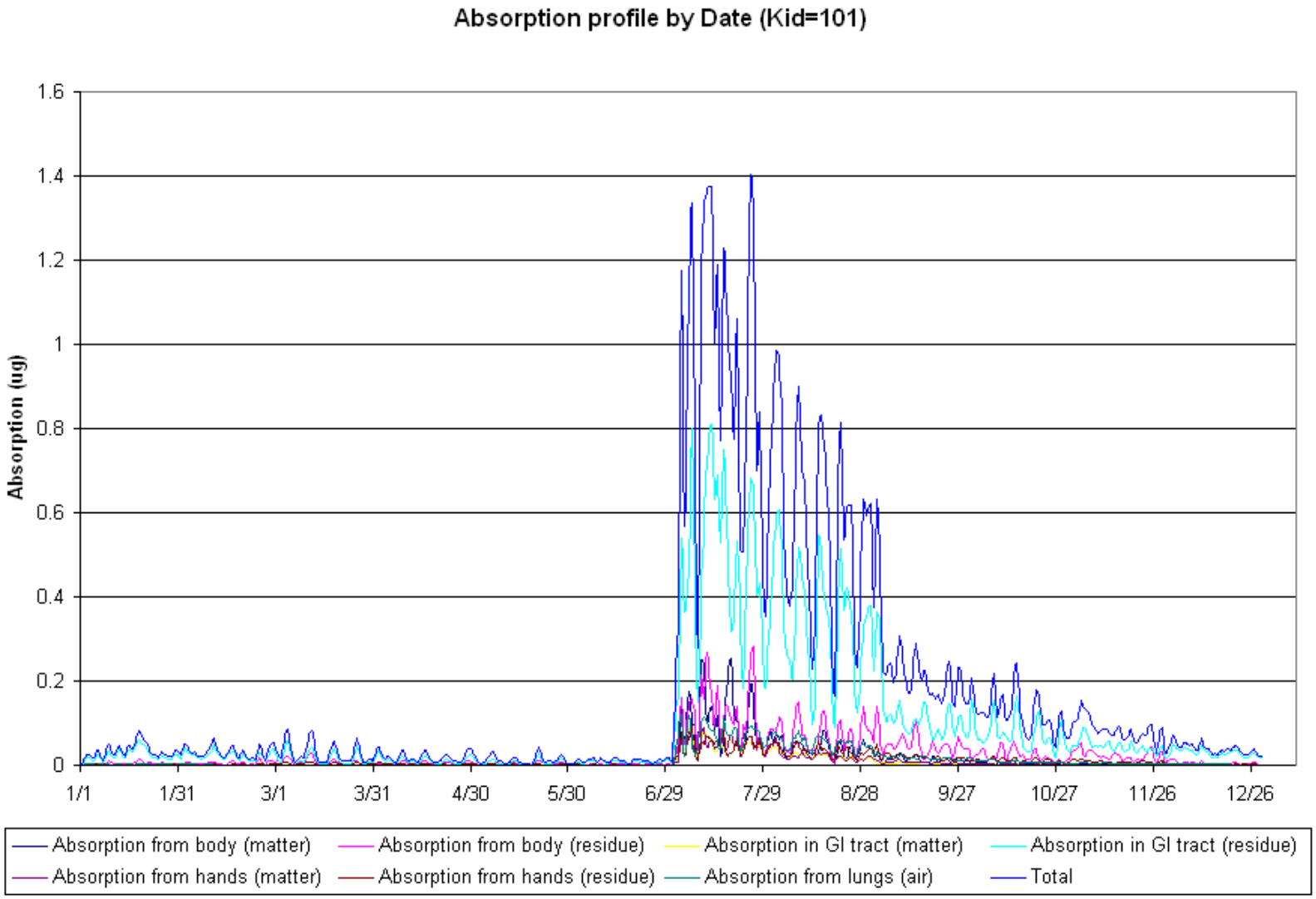


# 8) Generate dose time series for the individual (if using built-in PK model)

**A)**



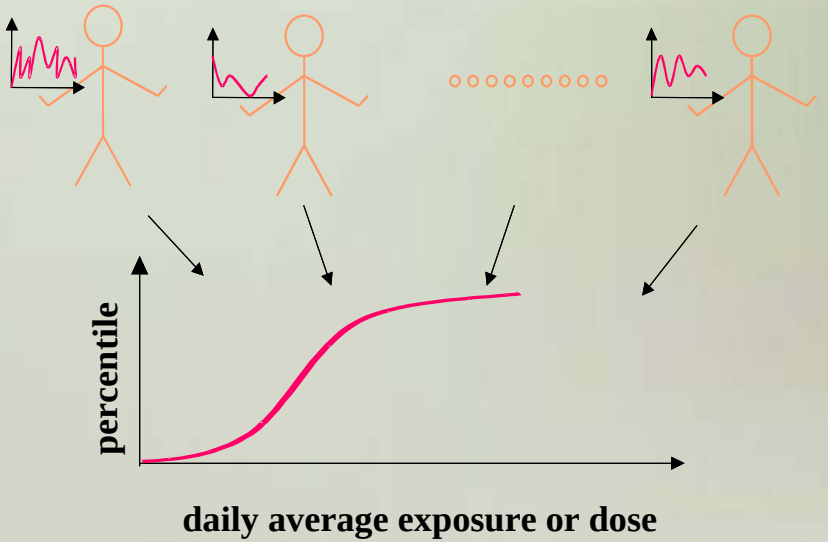
# Predicted Absorption Profiles from Indoor Crack and Crevice Application of a Hypothetical Pesticide



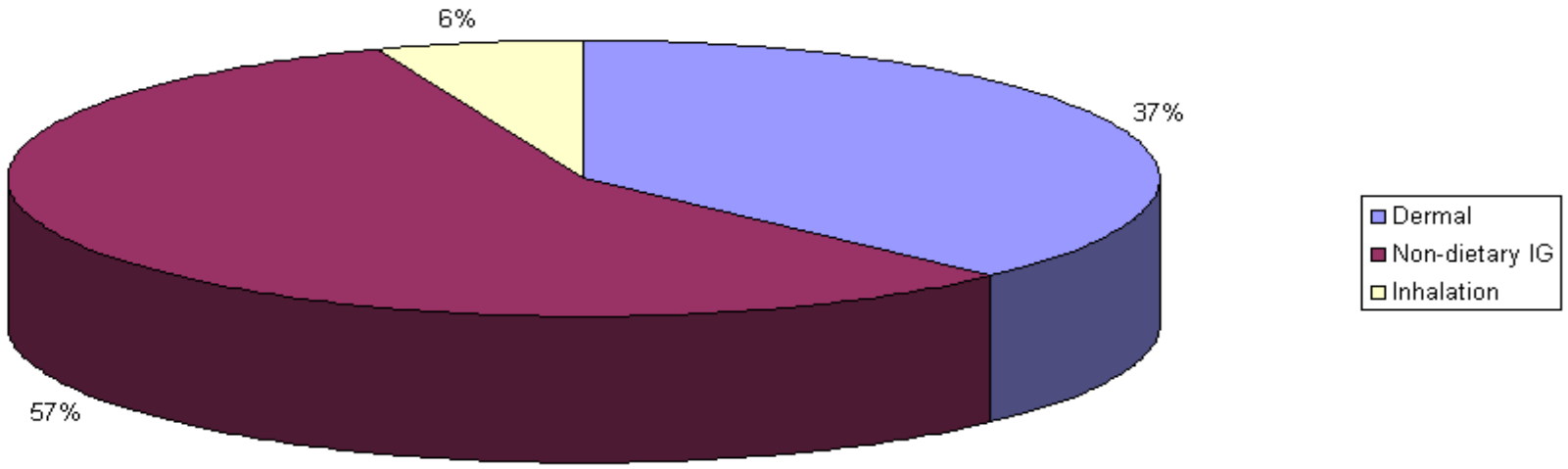
# 9) Extract exposure or dose time series

- Several types of variables
  - new or running exposure
  - new or running dose
  - eliminated dose
- Totals or contribution by route
  - dermal
  - hand-to-mouth
  - object-to-mouth
  - inhalation

# 10) Generate population variability estimates



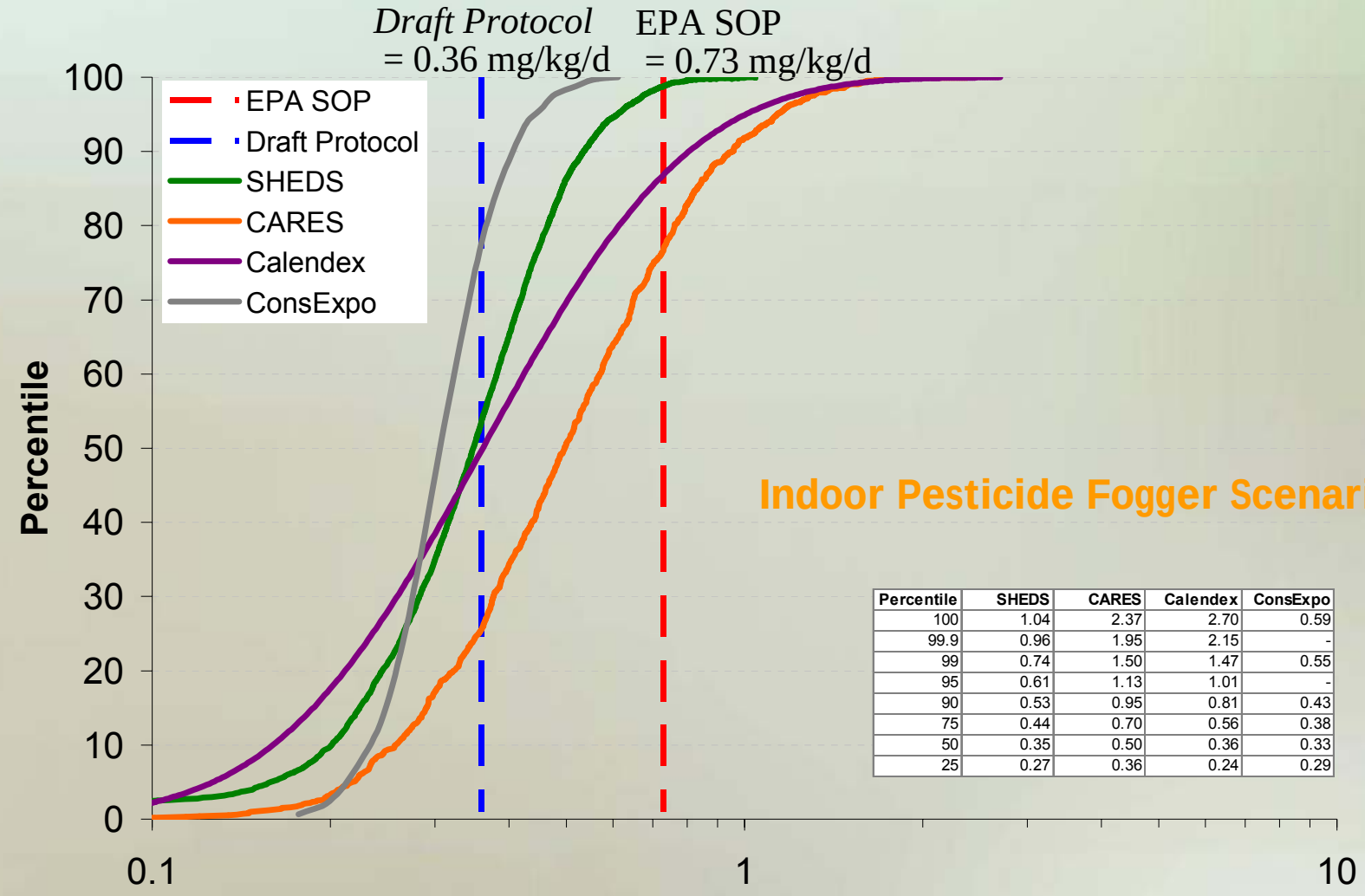
# Contribution of Different Exposure Pathways to Estimated Annual Average Absorption from Indoor Crack and Crevice Application of a Hypothetical Pesticide



# Model Evaluation: Comparing Different Dermal Algorithms

- **EPA Residential SOP Dermal Algorithm:**
  - $E = [C \times TC \times T\ ] / BW$
- *Draft Protocol* **Algorithm – Macroactivity Approach:**
  - $E = [C_x \times TC \times T] / BW$
- **CARES Dermal Algorithm:**
  - $E_{Adult/Child} = [C \times TC_{Adult/Child} \times T_{Adult/Child}] / BW$
- **SHEDS Transfer Coefficient Approach Algorithm:**
  - $E = [C \times TC_{hand/body} \times T \times Adj] / BW$

# Comparison of Dermal Exposure Predictions of Residential Human Exposure Models

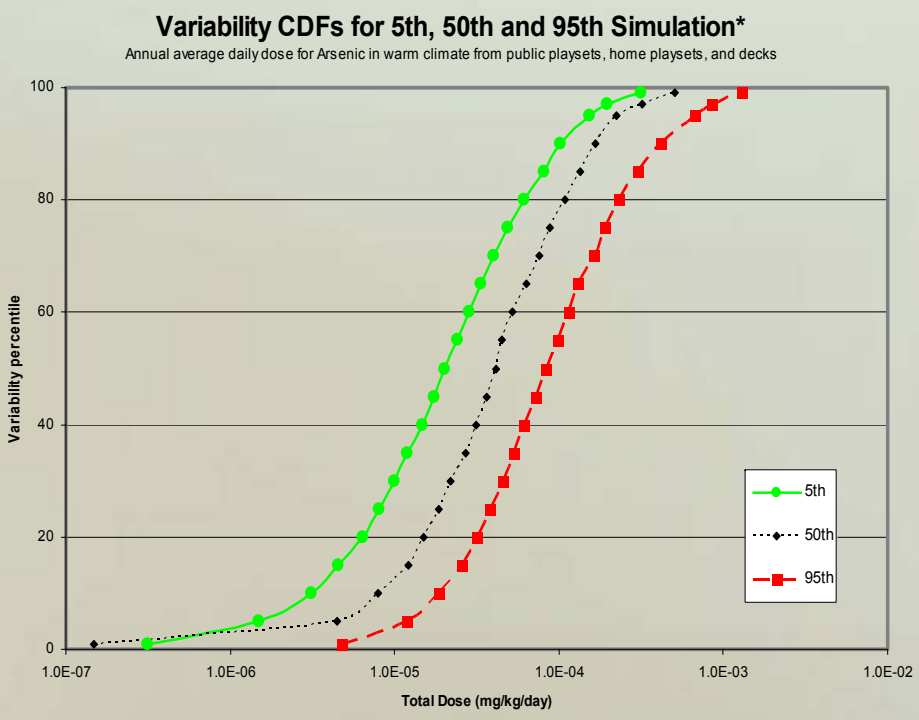


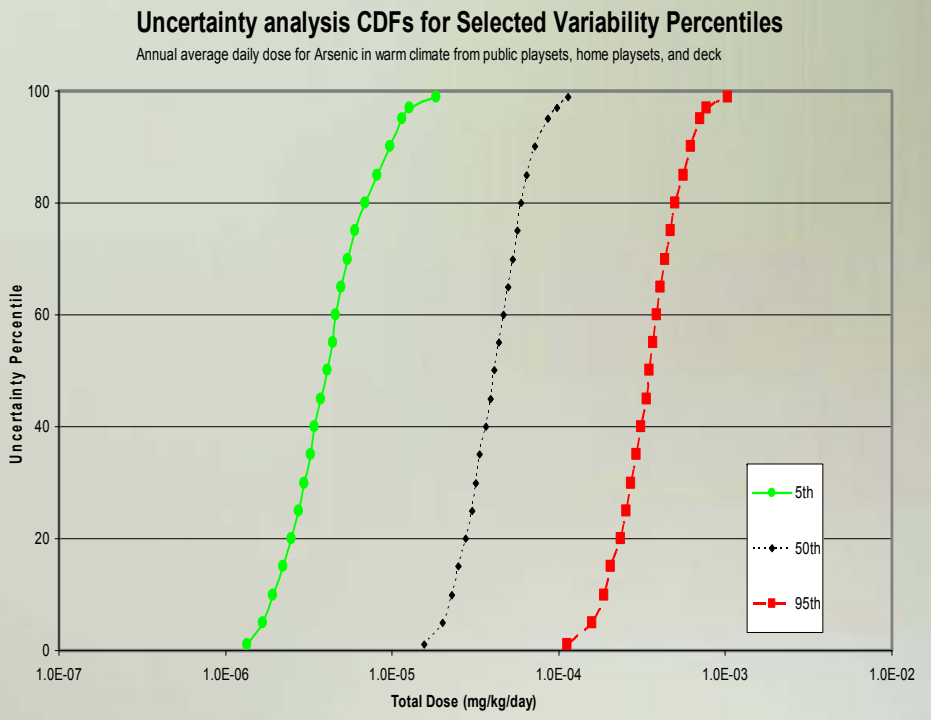

**Indoor Pesticide Fogger Scenario**

| Percentile | SHEDS | CARES | Calendex | ConsExpo |
|---|---|---|---|---|
| 100 | 1.04 | 2.37 | 2.70 | 0.59 |
| 99.9 | 0.96 | 1.95 | 2.15 | - |
| 99 | 0.74 | 1.50 | 1.47 | 0.55 |
| 95 | 0.61 | 1.13 | 1.01 | - |
| 90 | 0.53 | 0.95 | 0.81 | 0.43 |
| 75 | 0.44 | 0.70 | 0.56 | 0.38 |
| 50 | 0.35 | 0.50 | 0.36 | 0.33 |
| 25 | 0.27 | 0.36 | 0.24 | 0.29 |

**Source**: Young et al., 2008
ISEA Conference, Pasadena CA

# Modeled Uncertainties: CCA Case Study for Arsenic



# Case-Study 3: Modeling Dietary Exposures to Pesticides

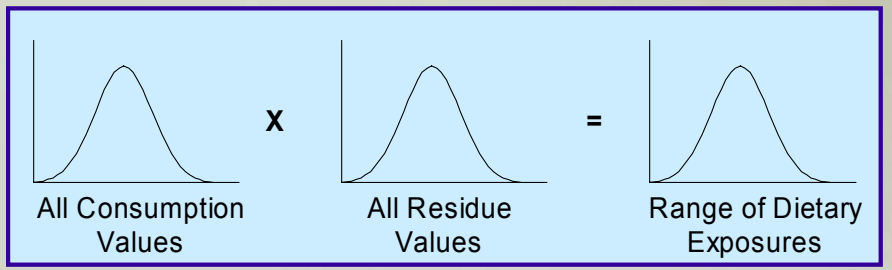
**Objectives**

- Discuss the two main contributors to dietary pesticide exposures: residues and food consumption
- Identify sources of food residue and consumption data
- Describe lower vs. higher tier dietary exposure modeling methods
- Describe the EPA/OPP methodology used for estimating residues in consumed foods
- Present an example of a SHEDS dietary model application for a group of pesticides*

* Contact Dr. Jianping Xue at EPA (xue.jianping@epa.gov) for information regarding accessing the SHEDS dietary model

# Modeling Dietary Exposures to Pesticides

- **Dietary exposure estimates are derived from two distinct pieces of information (food consumption and residues):**
  - USDA's Continuing Survey of Food Intake by Individuals (CSFII) or NHANES* food consumption data
  - the amount of pesticide in and on food (i.e., pesticide residues) which reflect
    - field trial data
    - monitoring data
      - USDA PDP and FDA
    - market basket survey
- **Degree of tiering depends on:**
    - Available data
    - Type of exposure assessment (acute, chronic)
    - Need for additional refinements




Modified from: David Hrdy, EPA/OPP

*Publicly available at http://www.cdc.gov/nhanes/

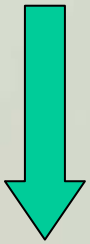
# Assessing Dietary Exposures and Risks

**Risk** is a function of Hazard & Exposure

**Exposure** = Residue x Consumption

Tolerance, Anticipated Residues

[Field Trials or Monitoring Data]



CSFII or NHANES Data

# Assessing Acute Dietary Exposures

- **Lower Tier**
- Single high end exposure using high end residue concentration (deterministic)
- **Higher Tier**
- Monte Carlo using the entire distribution of residues and food consumption (probabilistic)

# Estimating Residues in Food

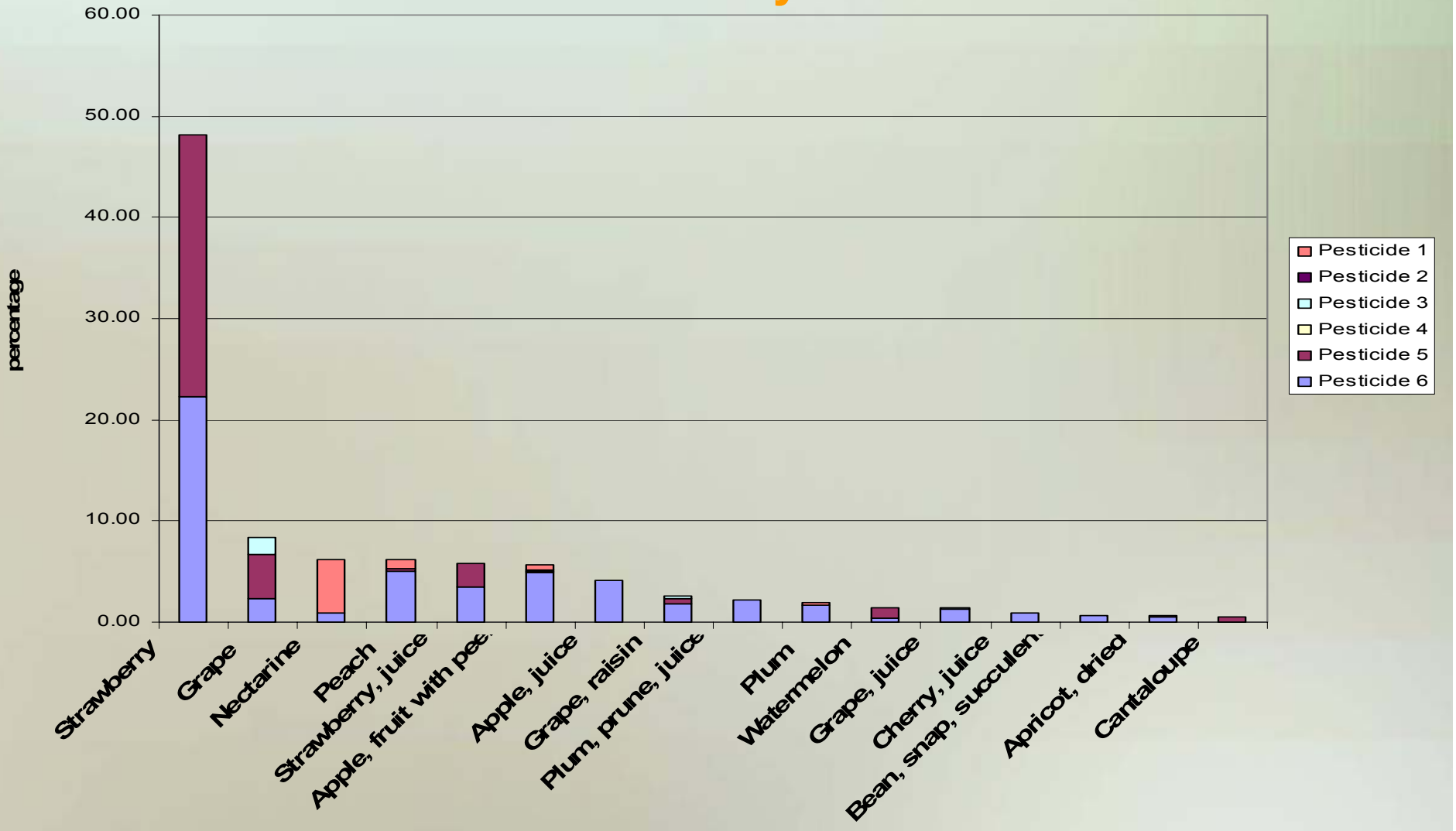
- CSFII and NHANES collected data on how much of each type of food was consumed each day (e.g., pizza, bread, apple pie, fruit juice) from 1- or 2-day diaries
- But residue data are on either raw agricultural commodities (RACs) or processed commodities, not prepared meals
- Recipe files are used to relate residue data on RACs to estimated residues on food items eaten

# Creating Recipes from RACs: Apple Pie Example

Apple Pie — 100 g

- Flour — 34 g → Wheat
- Butter — 1 g → Milk
- Sugar — 15 g → Sugar Beets
- Apples — 50 g → Apples

# Contributions to Upper-End Dietary Exposures of 1-2 year old Children from Different Pesticides in RACs Predicted by the SHEDS-Dietary Model



# Lessons Learned and Modeling Challenges

- Importance of air exchange rate on residential infiltration and the need for surrogate measures in absence of actual measurements
- Challenges involved in modeling longitudinal time-activity patterns based on single day observations available from CHAD data base
- Age-Specific Exposure Issues: do we have sufficient data for vulnerable populations (e.g., children, elderly)?
- Limitations of available pesticide use and residue measurement data
- Importance of measuring key covariates that reduce uncertainties in exposure modeling or comparison to biomonitoring data: food consumed, last food intake time, urinary volume
- How can we verify the model results (e.g., scarcity of personal exposure data for PM and the limitations of biomarker data for evaluating exposures to pesticides)?
- How can we effectively communicate exposure model results and associated uncertainties to risk assessors and decision-makers?

# Disclaimer

Although this work was reviewed by EPA and approved for publication, it may not necessarily reflect official Agency policy