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RAQM-5 Hong Kong Forum

Opportunities in the Greater Bay Area – Regional Collaboration & Exposure Management Breakthrough

Exposure to Air Pollution and Health Implications

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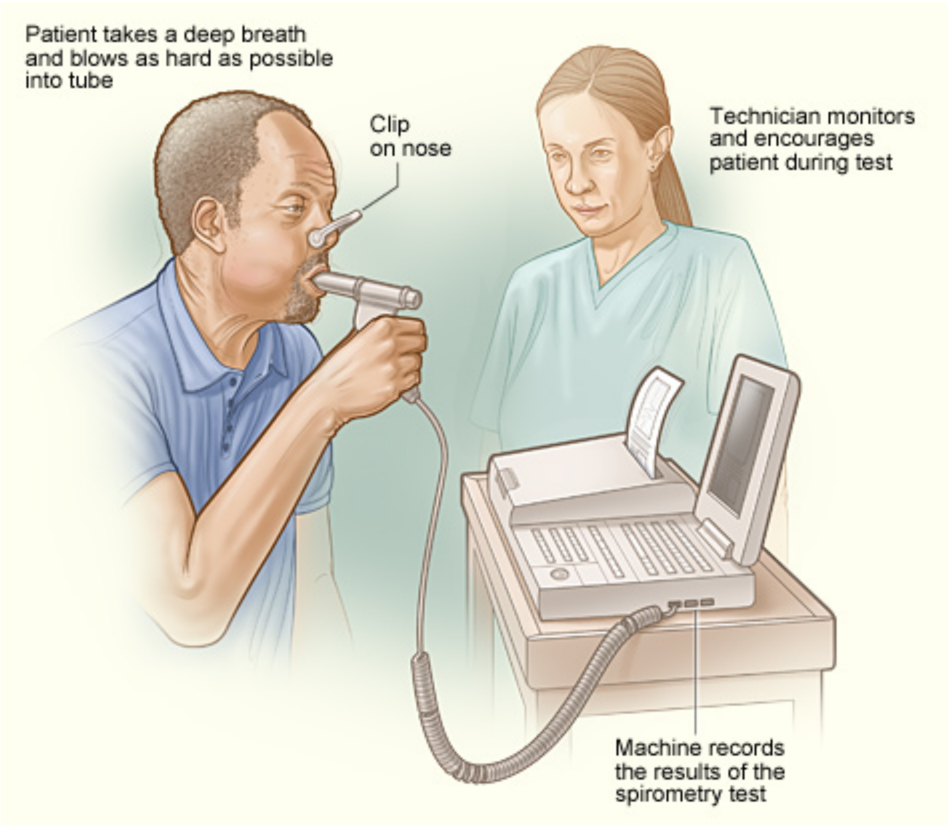
Overview

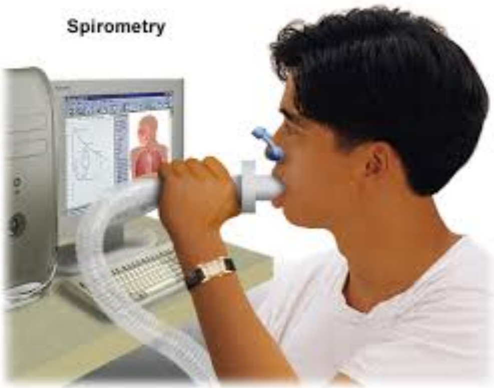
- Types of scientific evidence used to assess the hazards to health from exposure to air pollution
- Most people spend over 80% of their time in enclosed microenvironments (home, bus, school, etc.)
- Most exposure to ambient pollution takes place in enclosed microenvironments
- Hence, actual exposure is determined by targetable factors including emissions, dispersion, built environment, infiltration, and activity patterns
- There are more ways to manage exposure than just managing emissions

Air Pollution Harms Public Health – But How Do We Know This?

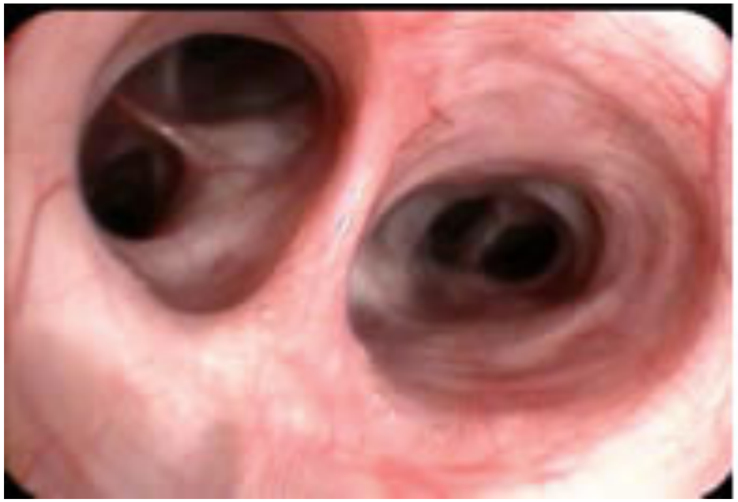
- Controlled experiments with human subjects
  - Usually healthy subjects, lower exposure concentrations, short-term effects, cannot look at very severe outcomes
- Epidemiologic studies
  - Statistical models for large populations
  - Uncertainties related to possible other causes
- Toxicologic studies
  - Controlled laboratory experiments with animals such as mice, rats
  - Useful for causality and "mode of action"

Spirometry


Patient takes a deep breath and blows as hard as possible into tube
Clip on nose
Technician monitors and encourages patient during test
Machine records the results of the spirometry test


Spirometry

Airway Inflammation



Confidence Intervals Around $PM_{2.5}$ Concentration-Response Relationships – Information from Multi-city Epidemiological Studies

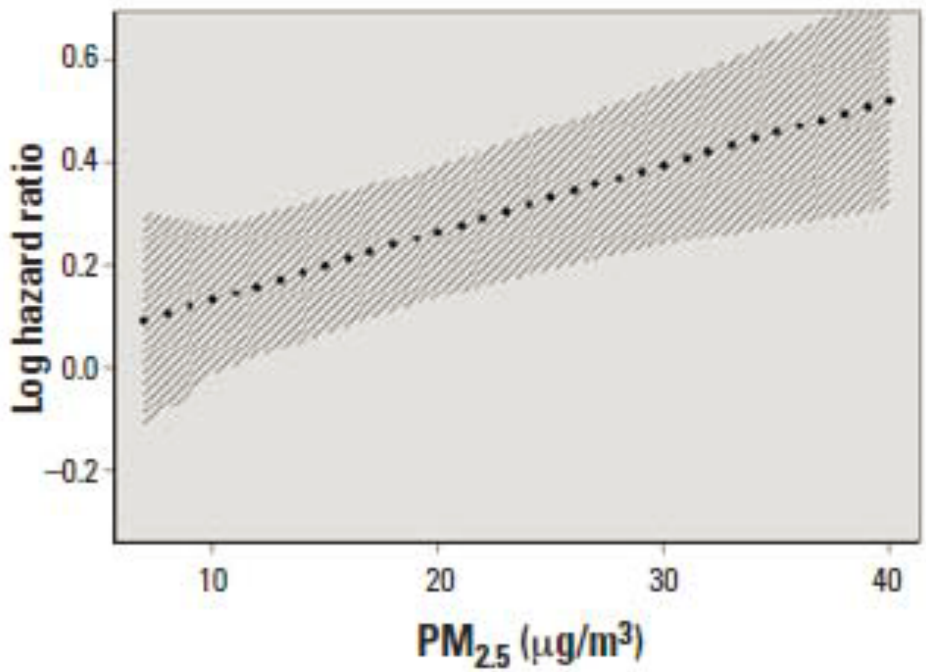


Figure 2. The estimated concentration–response relation between $PM_{2.5}$ and the risk of death in the Six Cities Study, based on averaging the 32 possible models that were fit. Also shown are the pointwise 95% CIs around that curve, based on jacknife estimates.

Source: EPA Risk and Exposure Assessment for PM

How Do We Determine that Exposure to Air Pollution *Causes* Harm?

- Rule out chance, confounding, and other biases
- "Consistent" results between multiple studies of a given type (e.g., epidemiologic)
- "Coherent" results when comparing different types of studies (e.g., controlled human studies and epidemiologic studies)
- "Biological plausibility" – there is a "mode of action" by which the pollutant enters the body and causes harm to tissues or organs

Matrix of Causal Determinations from Recent U.S. Air Quality Science Assessments

		Causality Determination					
Outcome Category	Exposure Period	NO_2 (2008 ISA)	SO_2 (2008 ISA)	$PM_{2.5}$ (2009 ISA)	$PM_{10-2.5}$ (2009 ISA)	CO (2010 ISA)	O_3 (2013 ISA)
Cardiovascular Morbidity	Short-term	Inadequate	Inadequate	**Causal**	Suggestive	Likely Causal	Likely Causal
Respiratory Morbidity	Short-term	Likely Causal	**Causal**	Likely Causal	Suggestive	Suggestive	**Causal**
Mortality	Short-term	Suggestive	Suggestive	**Causal**	Suggestive	Suggestive	Likely Causal
Cardiovascular Morbidity	Long-term	Inadequate	Inadequate	**Causal**	Inadequate	Inadequate	Suggestive
Respiratory Morbidity	Long-term	Suggestive	Inadequate	Likely Causal	Inadequate	Inadequate	Likely Causal
Developmental and Birth Outcomes	Long-term	Inadequate	Inadequate	Suggestive	Inadequate	Suggestive	Suggestive
Mortality	Long-term	Inadequate	Inadequate	**Causal**	Inadequate	Suggestive of No Causal Relationship	Suggestive

Burden of Proof to Develop Air Quality Regulations

- In the U.S., we develop air quality standards that are "requisite to protect public health" with an "adequate margin of safety"
  - Intended to address uncertainties
  - Reasonable degree of protection
  - Should protect the general public and highly exposed or highly sensitive groups within the public – e.g., children, outdoor workers, elderly
  - Does not require zero risk for every member of a highly exposed or sensitive group
  - Interpretation has been reviewed in numerous court cases

Microenvironment

Surroundings for which air pollutant concentration is homogeneous or well characterized (e.g., home, office, automobile, kitchen store).

http://sphweb.bumc.bu.edu/otlt/mph-modules/ExposureAssessment/exposureassessment3.html

Outdoor Microenvironments

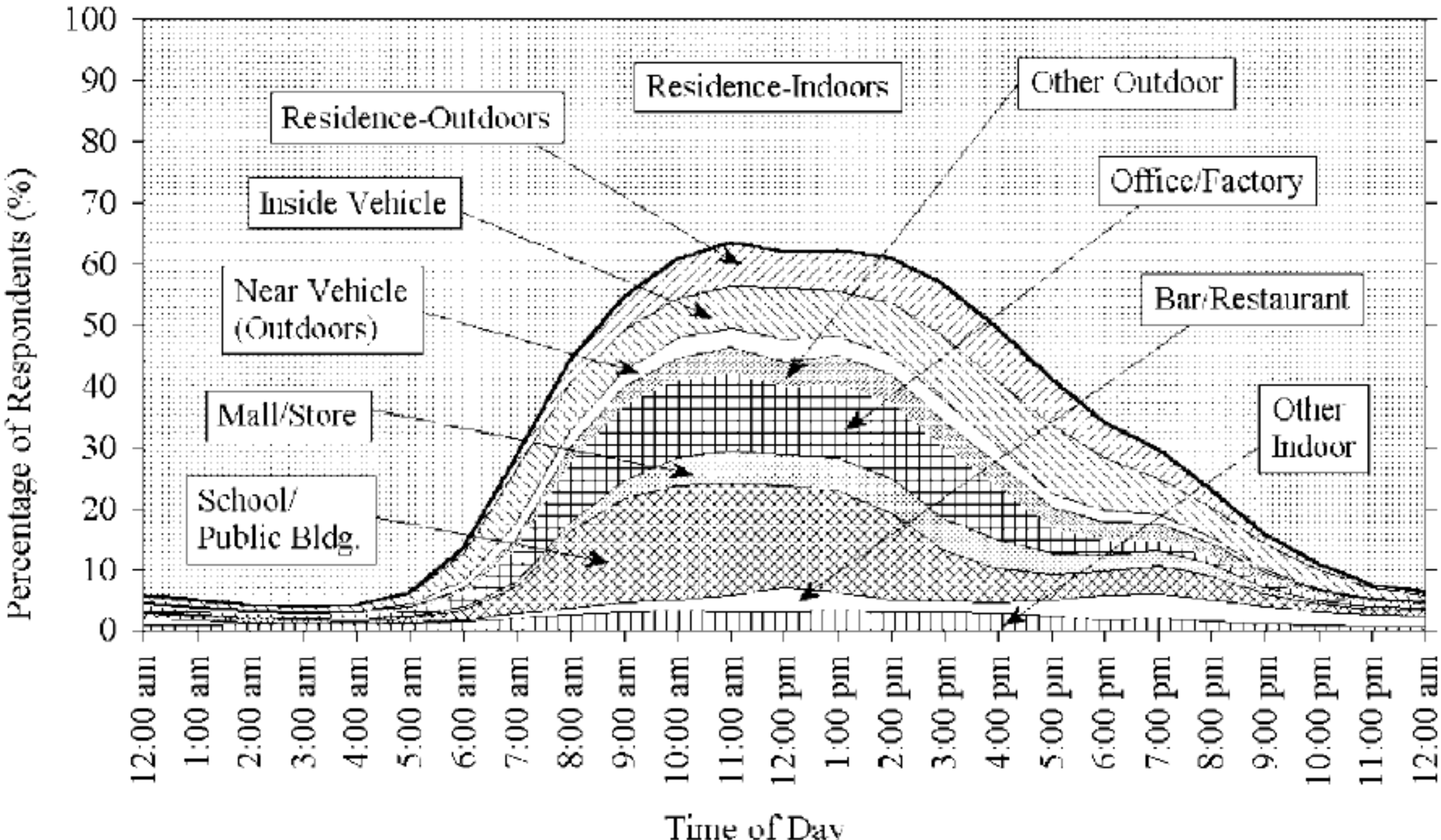
- Fixed site air quality monitor
- Example: Yuen Long General Station in Hong Kong

Outdoor Microenvironments: Near Road

Our Current Location: Indoors

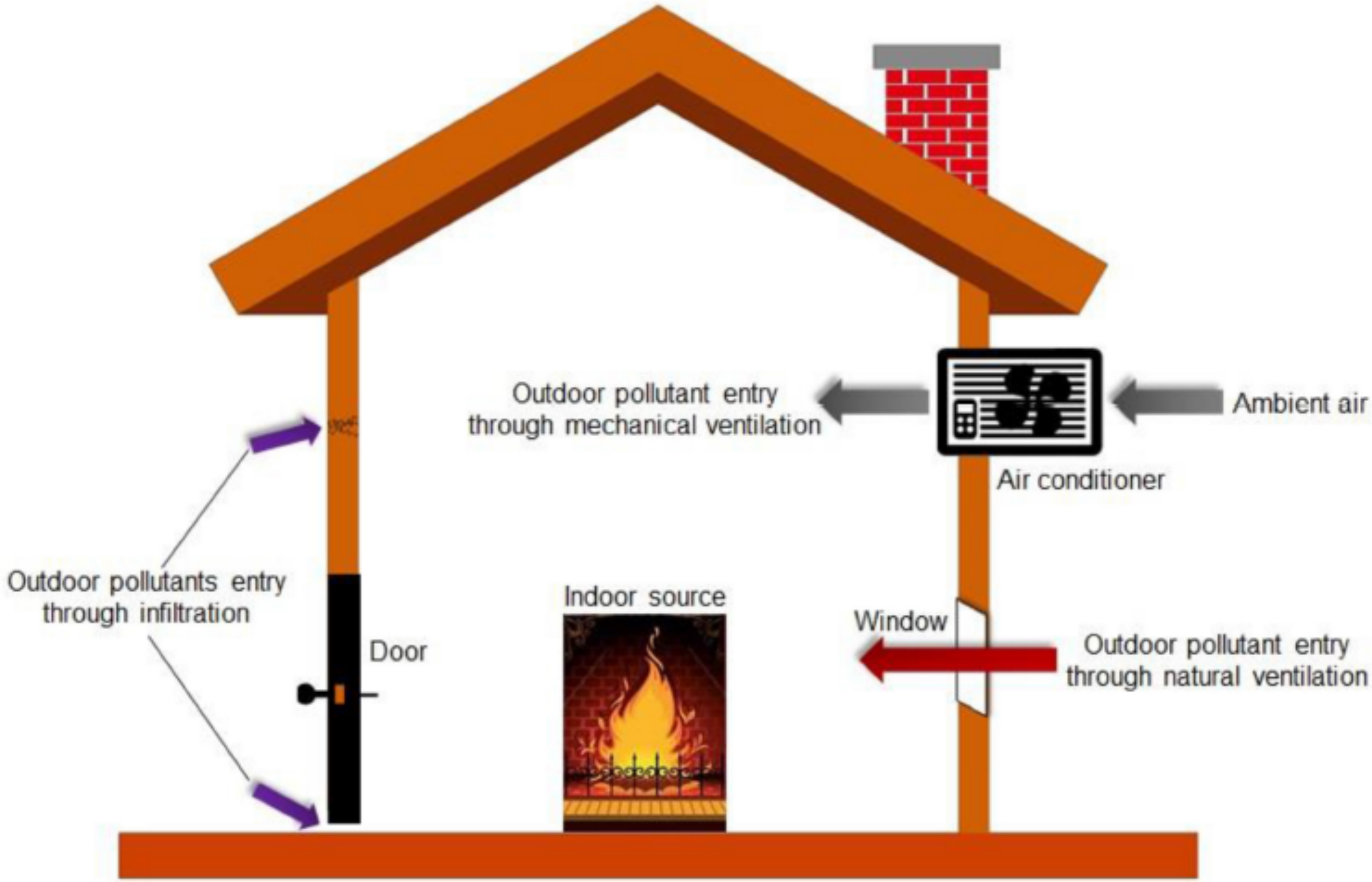
Although we are indoors, we are exposed to air pollution from outdoors

People Spend Most of Their Time Indoors



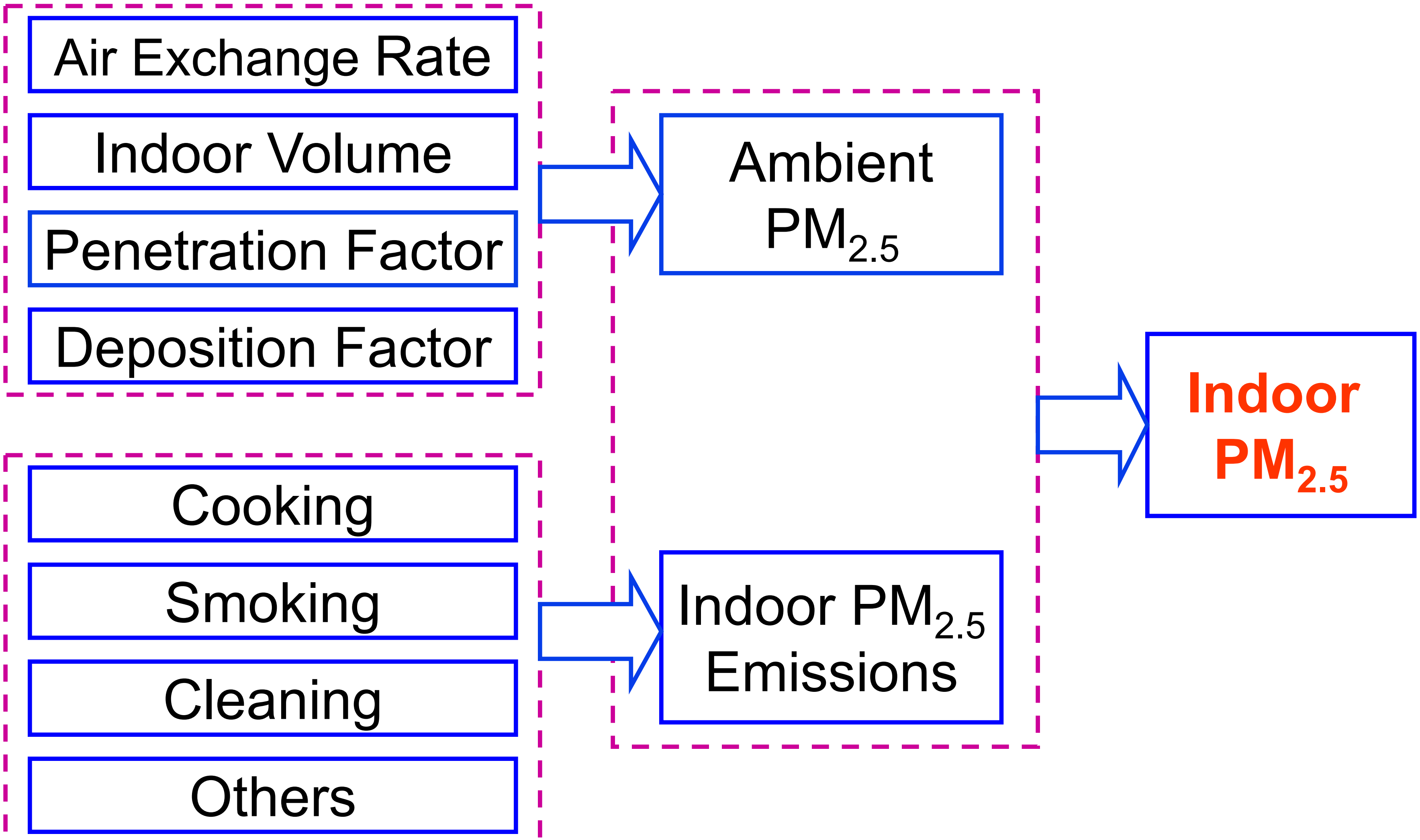
Klepeis et al., 2001

Sources and Pathways for Indoor Air Pollution

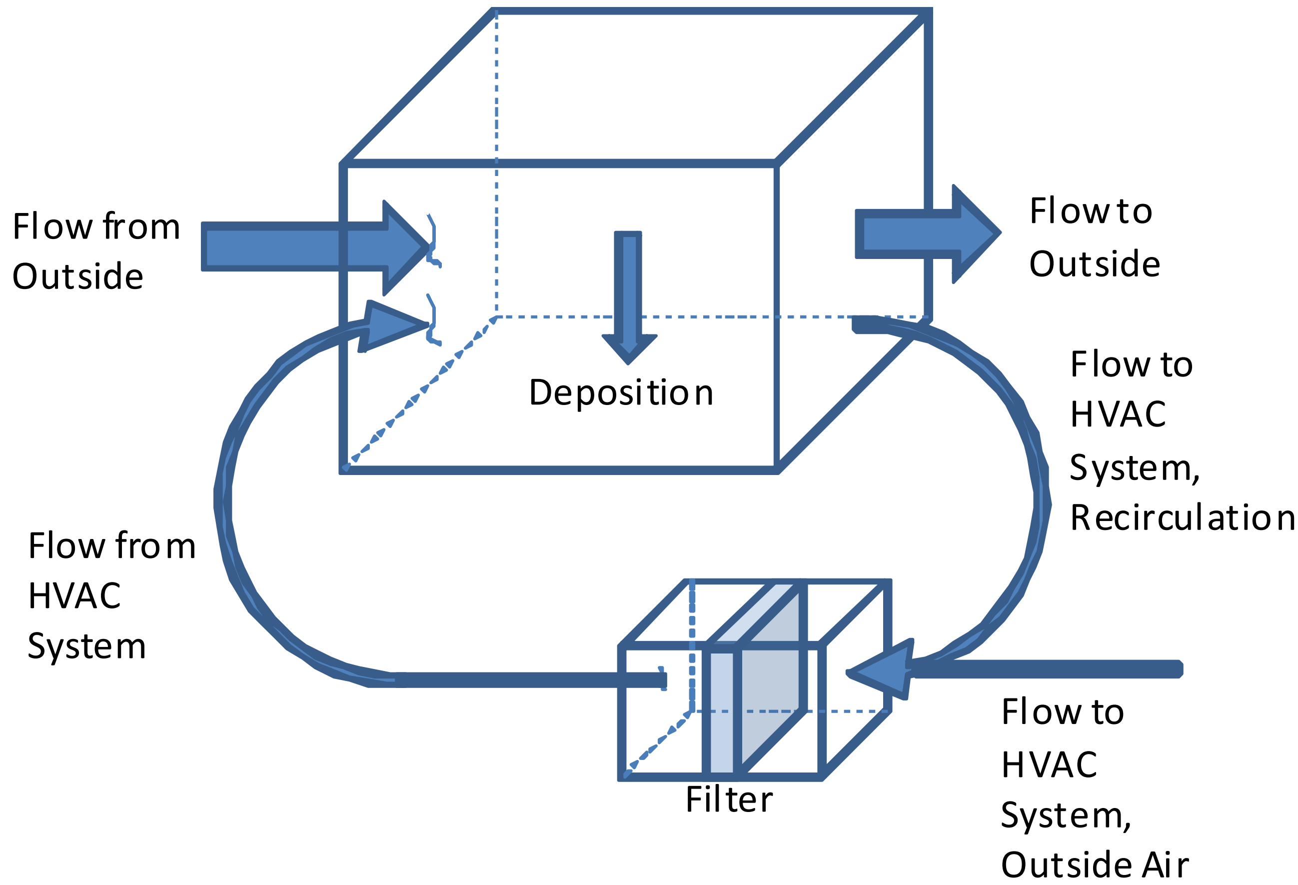


Leung, 2015

Conceptual Diagram of an Indoor Residential Microenvironment Model



Exposure Inside a Home or Vehicle: Example of a Mass Balance Model

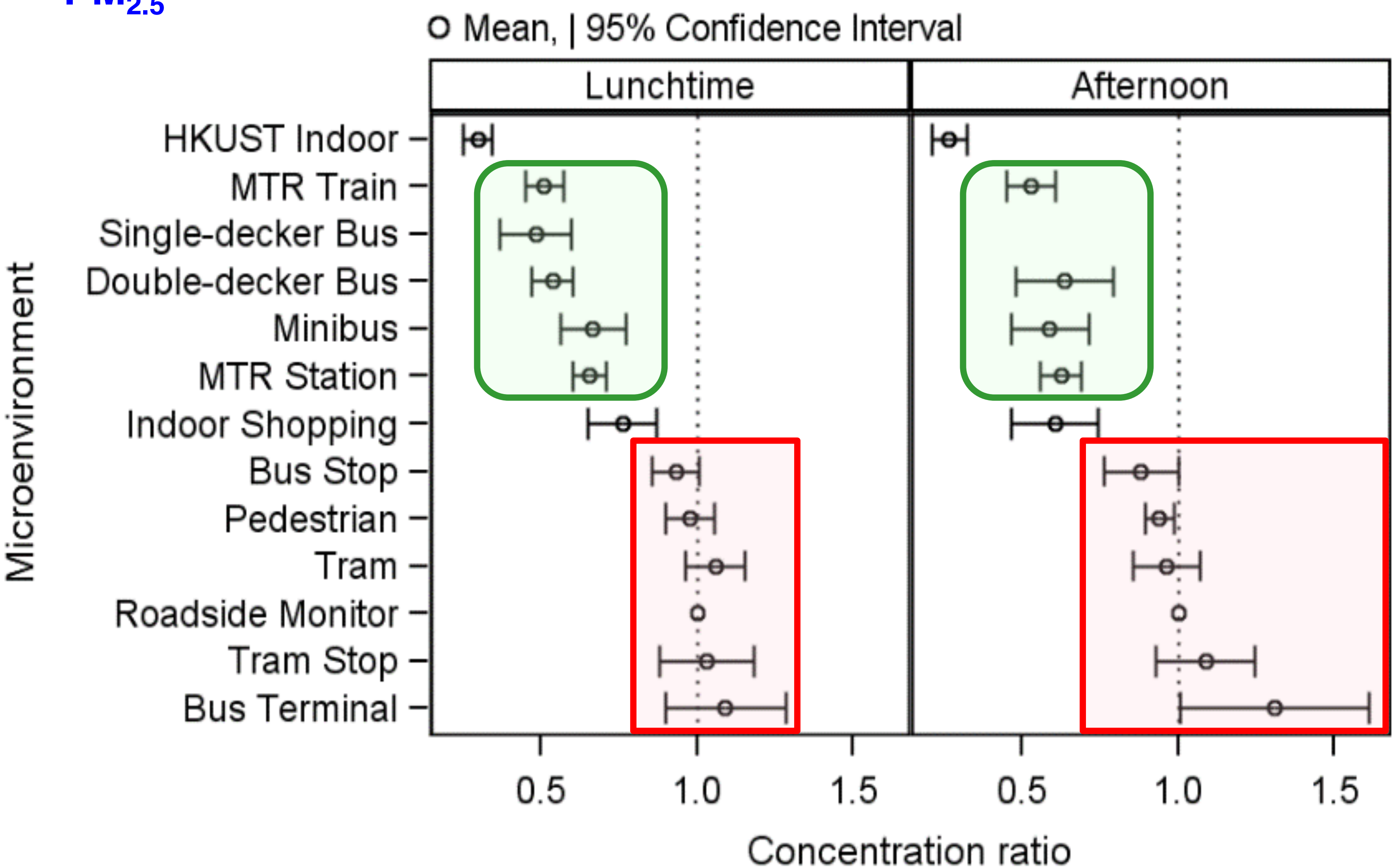


Average in- to near-vehicle concentration (I/O) ratio by route and ventilation condition

Case	Air Source	Window	Fan	AC	Route	Road Type	I/O Ratio (C_{IV}/C_{NV})
1-1	F	3"	0	off	A-out	NF	**0.98 ± 0.010**
1-2	F	closed	0	off	A-in	NF	**0.94 ± 0.001**
1-3	F	closed	1	off	1-out	10%NF / 90%F	**0.95 ± 0.007**
1-4	F	closed	1	on	1-in	90%F / 10%NF	**0.89 ± 0.044**
1-5	F	closed	3	off	C-out	half NF / half F	**0.91 ± 0.002**
1-6	F	closed	3	on	C-in	half F / half NF	**0.87 ± 0.037**
1-7	F	closed	4	off	3-out	NF	**0.90 ± 0.020**
1-8	F	closed	4	on	3-in	NF	**0.87 ± 0.002**
2-1	R	fully	0	off	A-out	NF	**0.97 ± 0.028**
2-2	R	closed	0	off	A-in	NF	**0.66 ± 0.003**
2-3	R	closed	1	off	1-out	10%NF / 90%F	**0.81 ± 0.033**
2-4	R	closed	1	on	1-in	90%F / 10%NF	**0.69 ± 0.035**
2-5	R	closed	3	off	C-out	half NF / half F	**0.64 ± 0.012**
2-6	R	closed	3	on	C-in	half F / half NF	**0.36 ± 0.082**
2-7	R	closed	4	off	3-out	NF	**0.47 ± 0.031**
2-8	R	closed	4	on	3-in	NF	**0.30 ± 0.024**

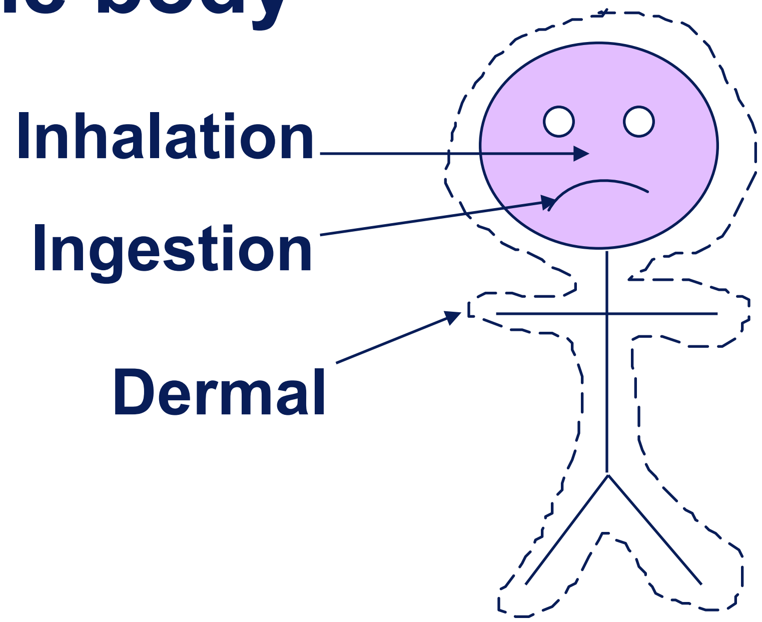
Variations in Micro Envir. Concentration

$PM_{2.5}$



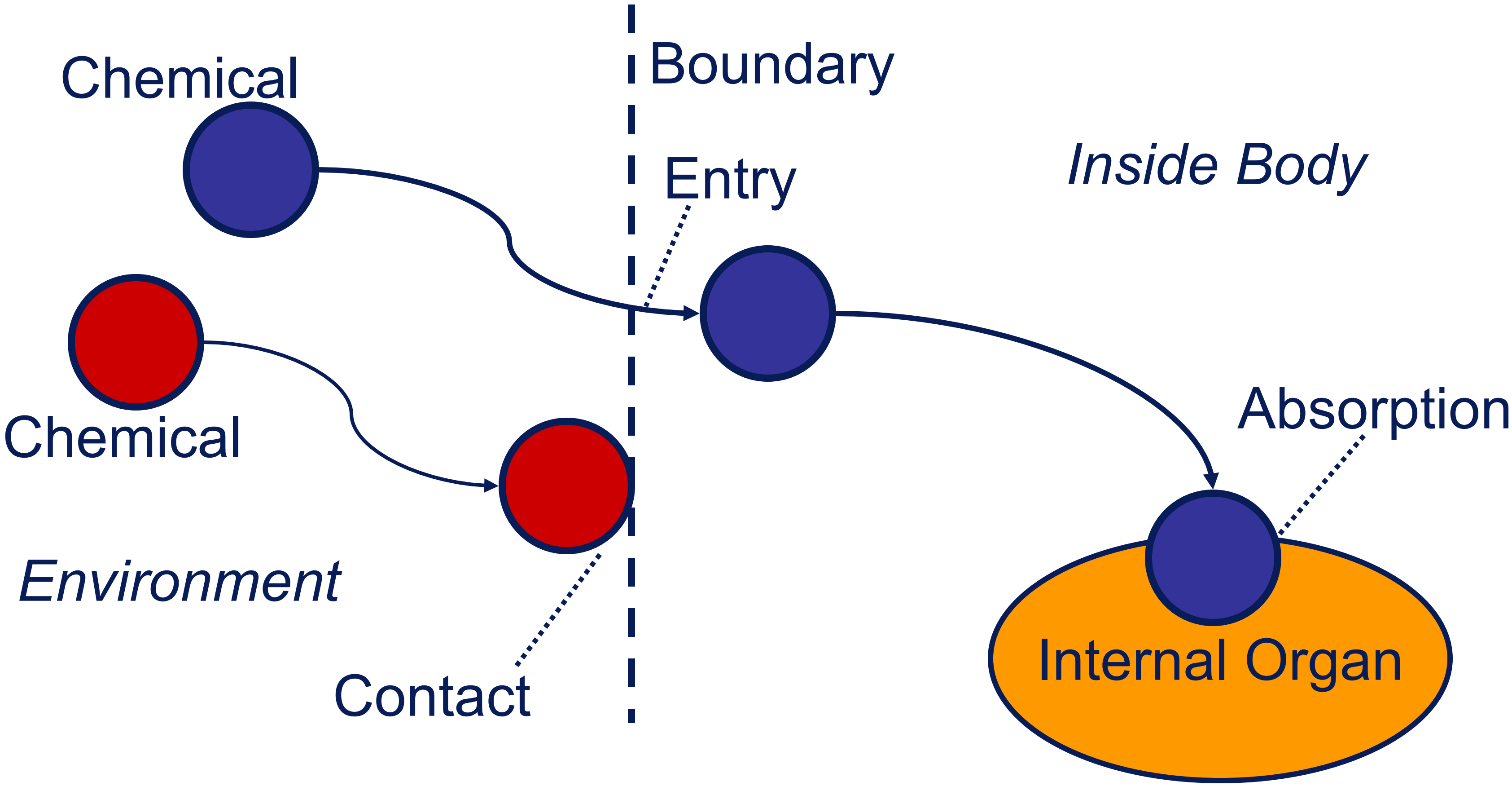
Exposure Assessment

- Contact of chemicals with the outer boundary of the body



Exposure Assessment

- **Contact, Entry, and Absorption**



Human Exposure and Risk Analysis

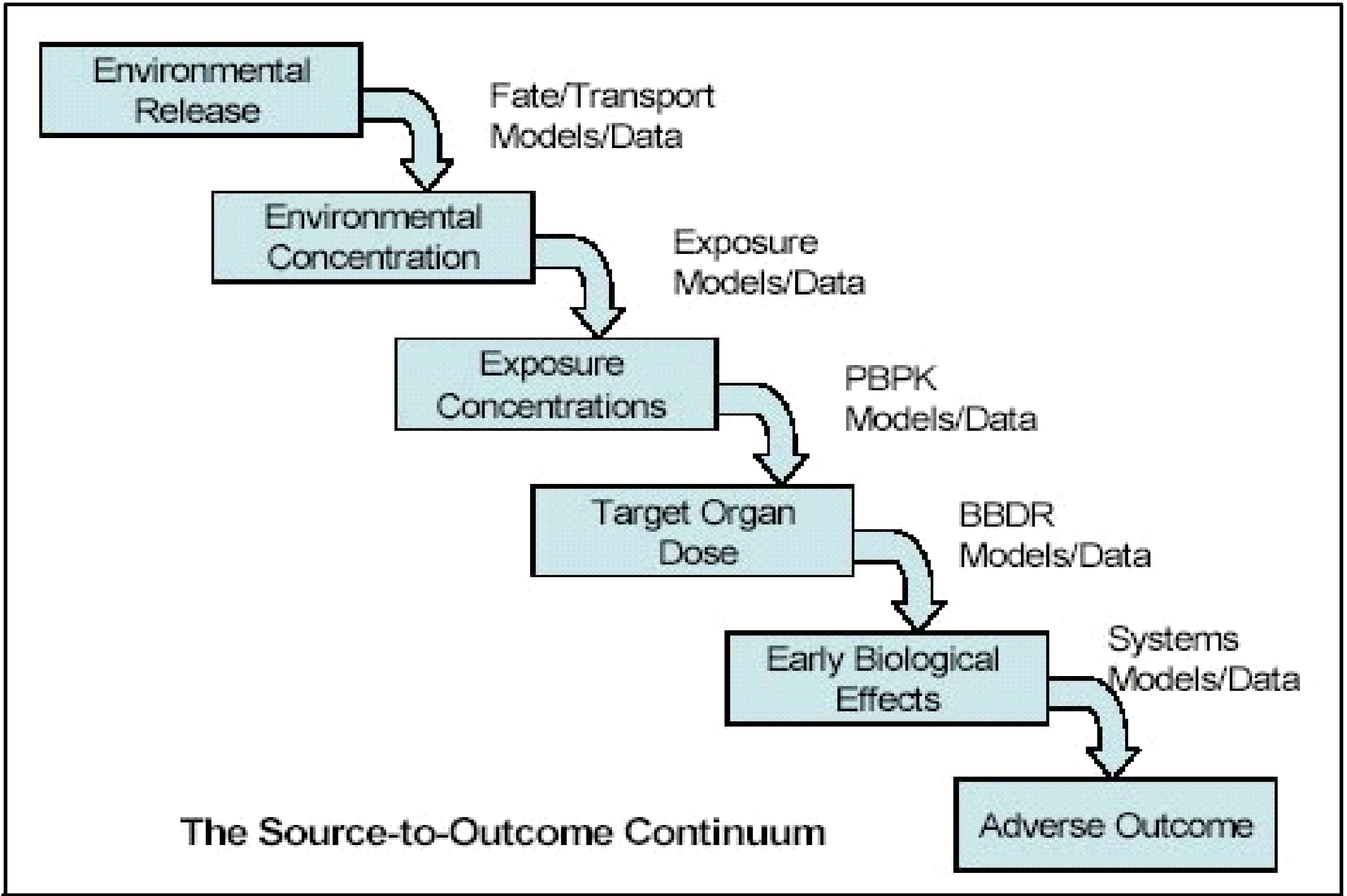
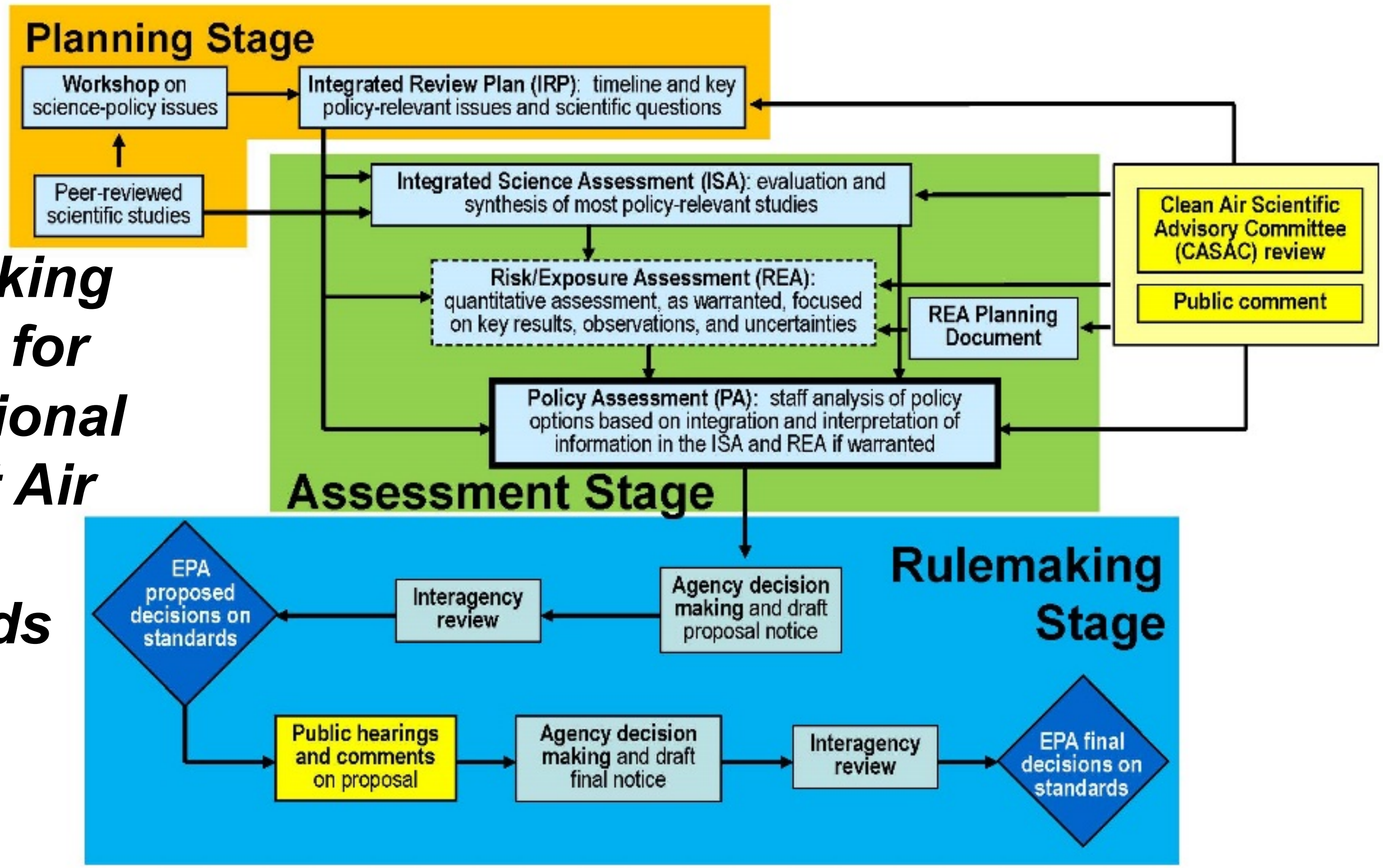


Figure 1. Modeling the Source to Outcome Continuum (EPA 2005)

The Role of Exposure Assessment in Linkage Between Air Pollution and Human Health

Rule-Making Process for U.S. National Ambient Air Quality Standards



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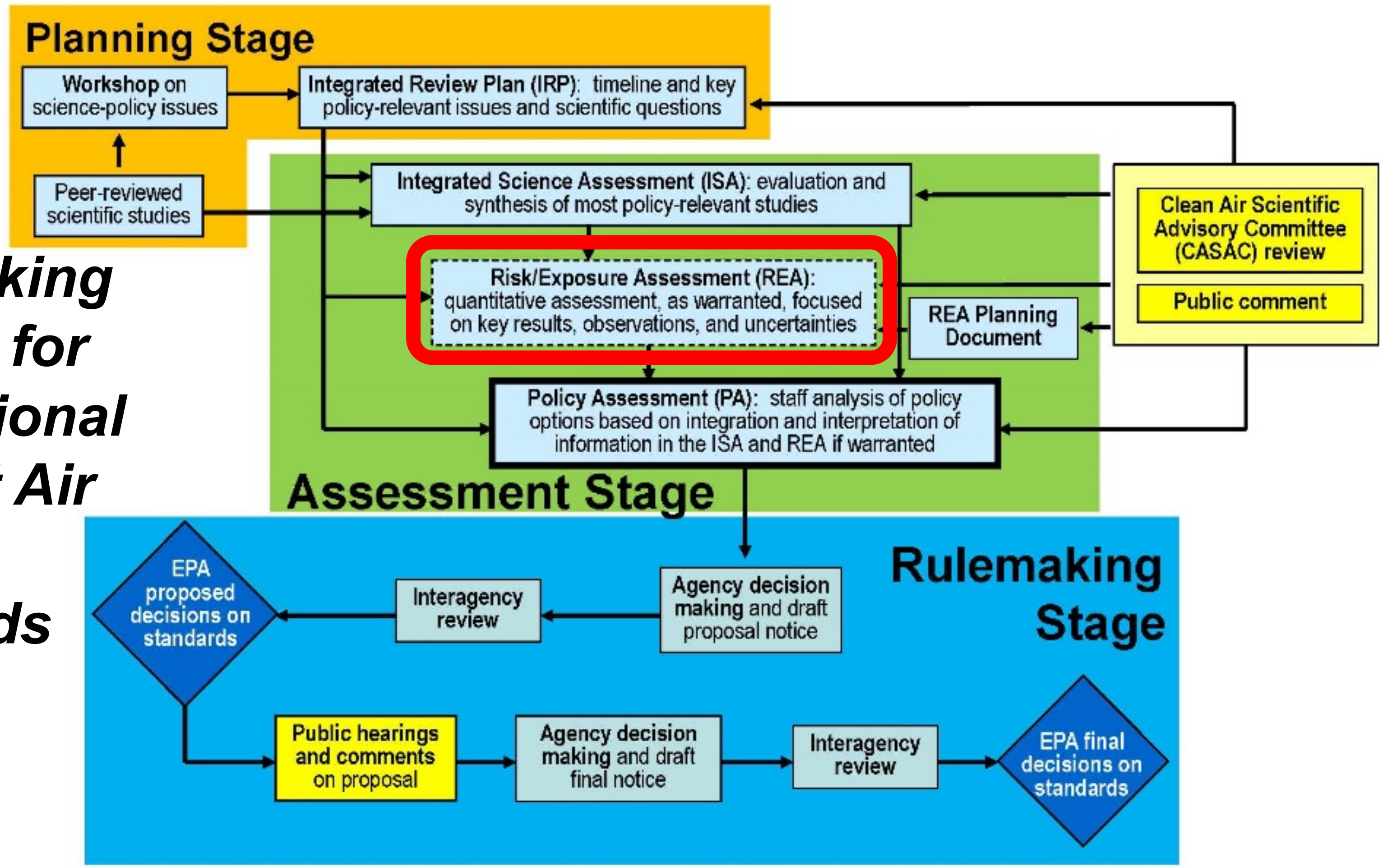

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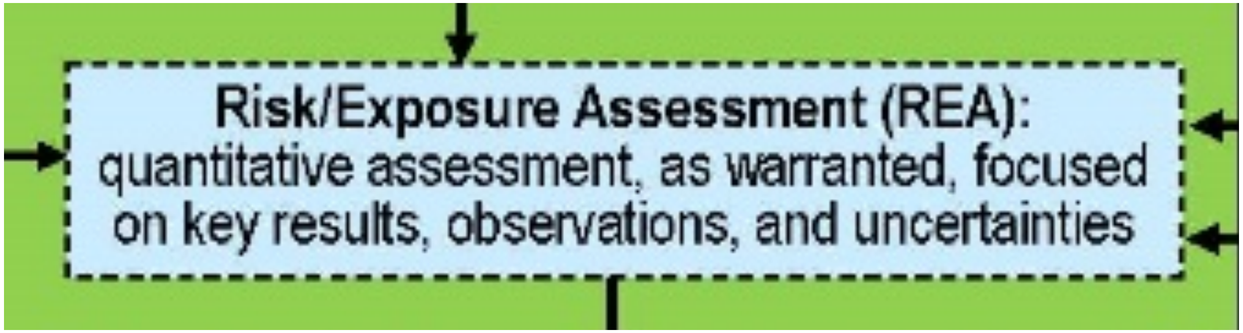


Examples of Key Questions to be Answered by the Exposure-based Methodology

- What are the **differences** in activities among individuals?
- What are the **activity patterns** for an individual over time?
- What is the **variability** in exposure concentration between microenvironments?
- **How sensitive are exposures** to time activity patterns and microenvironmental concentrations?
- **Which activities and microenvironments** contribute to the **highest exposures** among populations of interest?
- **Which sources** of variability in exposures are **controllable**, to enable **targeting** of effective management strategies?

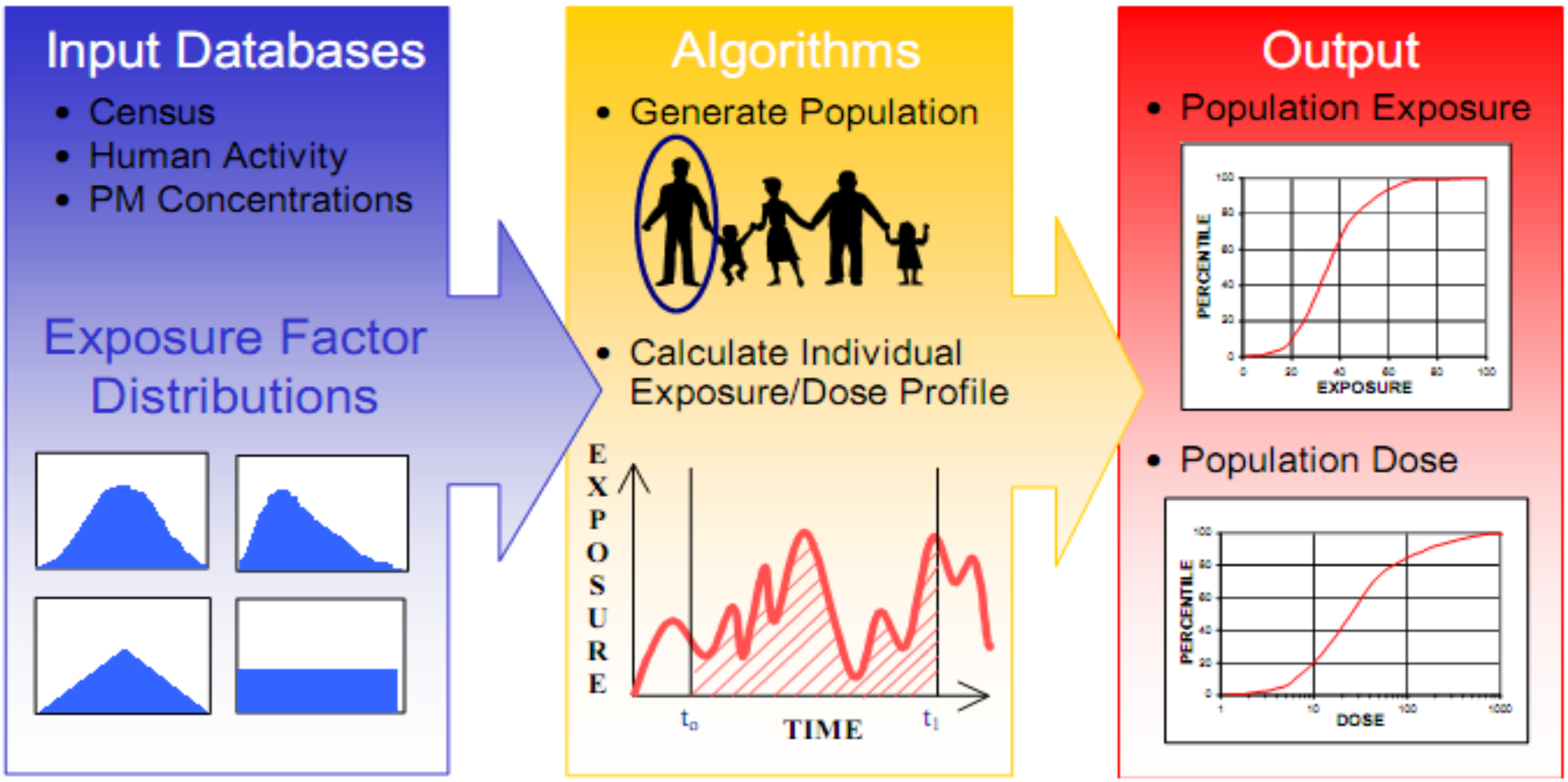
Recent Advances in Exposure Assessment Modeling

- Development of human diary databases – e.g., Consolidated Human Activity Database (CHAD) in the U.S.
- Measurement of selected microenvironments in U.S., Europe
- Development of stochastic population-based simulation models, such as
  - Air Pollution Exposure (APEX) model
  - Stochastic Human Exposure and Dose Simulation (SHEDS) model
- These models have the following key input:
  - Air quality data
  - CHAD
  - Census (demographic) data
  - Microenvironmental concentrations

Stochastic Population-Based Exposure Modeling

- State-of-the-art technique
- Developed and used by U.S. EPA to support revisions of National Ambient Air Quality Standards for criteria air pollutants
  - Carbon Monoxide (2010)
  - Lead (2007 and 2013)
  - Nitrogen Dioxide (2010, and current review cycle)
  - Ozone (2008 and 2014)
  - Sulfur dioxide (2009, and current review cycle)
  - PM (expected in upcoming review cycle)

Modeling Approach: Stochastic Human Exposure and Dose Simulation model for $PM_{2.5}$ (SHEDS-PM)



SHEDS-PM Model Structure

Source: Burke, J.M.; Vedamtham, R. *Stochastic Human Exposure and Dose Simulation for Particulate Matter (SHED-PM) Version 3.5 User Guide*; US Environmental Protection Agency: Research Triangle Park, NC, 2009.

Indoor Concentration Depends on Outdoor Concentration and Ventilation

$$C_r = \left(\frac{P \cdot ACH}{ACH + k} \right) C_a$$

Where

C_r = indoor residential ambient $PM_{2.5}$ concentration ($\mu g/m^3$)

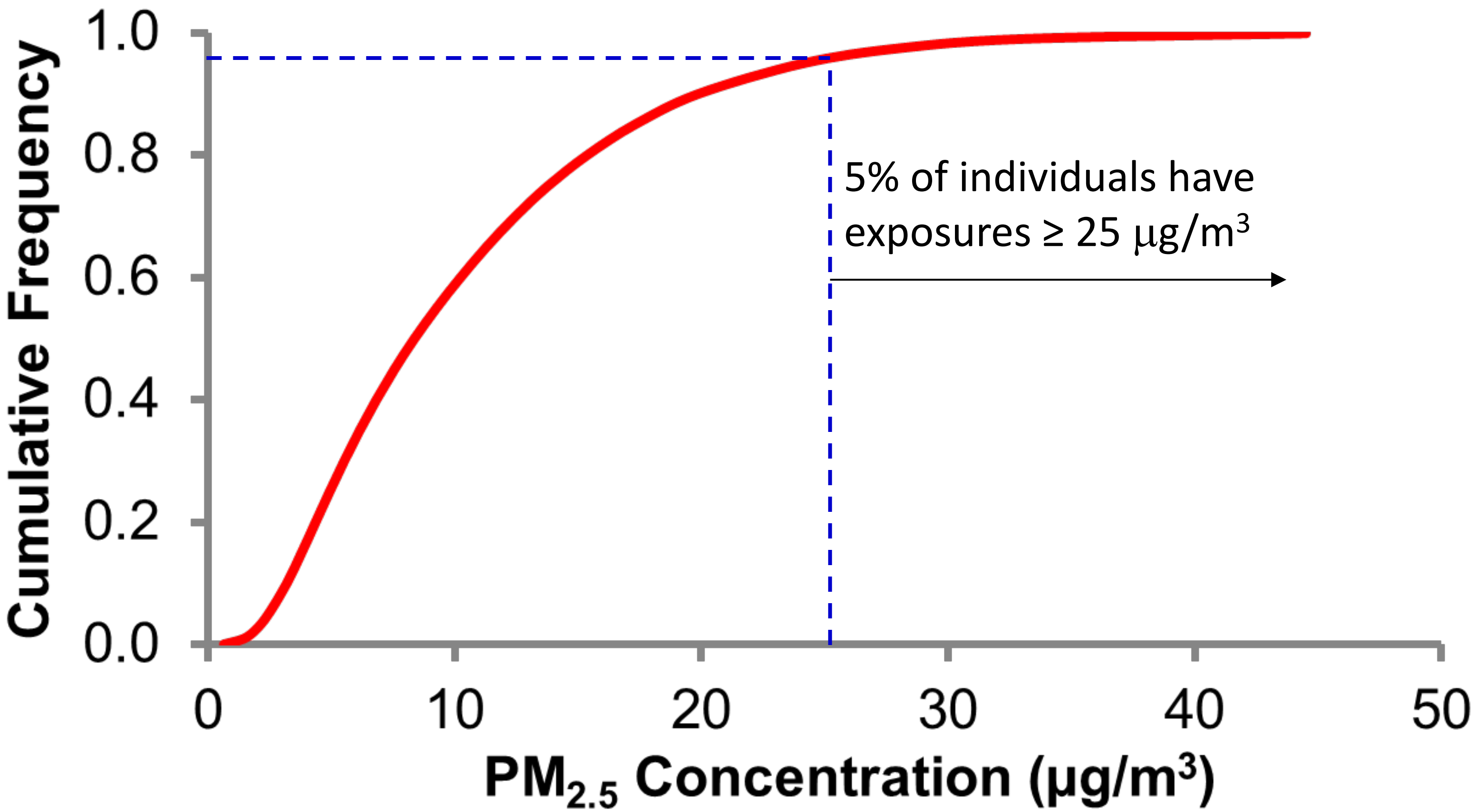
C_a = ambient outdoor $PM_{2.5}$ concentration ($\mu g/m^3$)

P = penetration factor (unitless)

ACH = air exchange rate (h^{-1})

k = deposition factor (h^{-1})

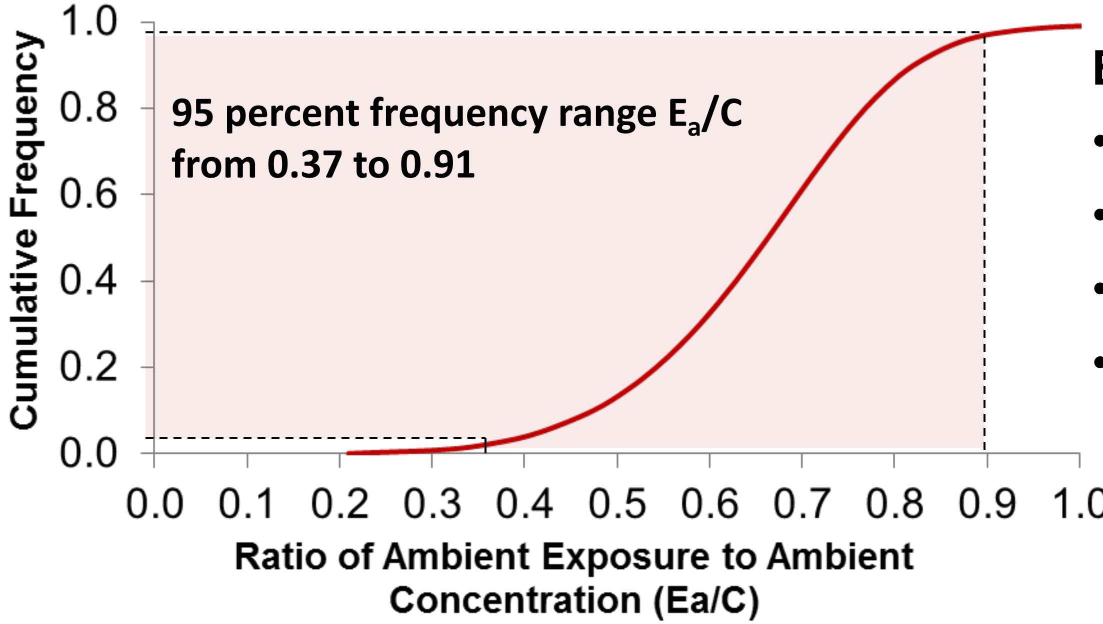
Example: Cumulative Distribution Function (CDF) of Inter-individual Variability in Daily Average Exposure (E_a)



New York city example from Jiao and Frey (2013)

Using a stochastic population based exposure model

Factors Affecting Inter-Individual Variability in $PM_{2.5}$ Exposure



E_a/C ratio is correlated with

- Residential air exchange rate
- Time spent at home
- Time spent in vehicle
- Time spent outdoors

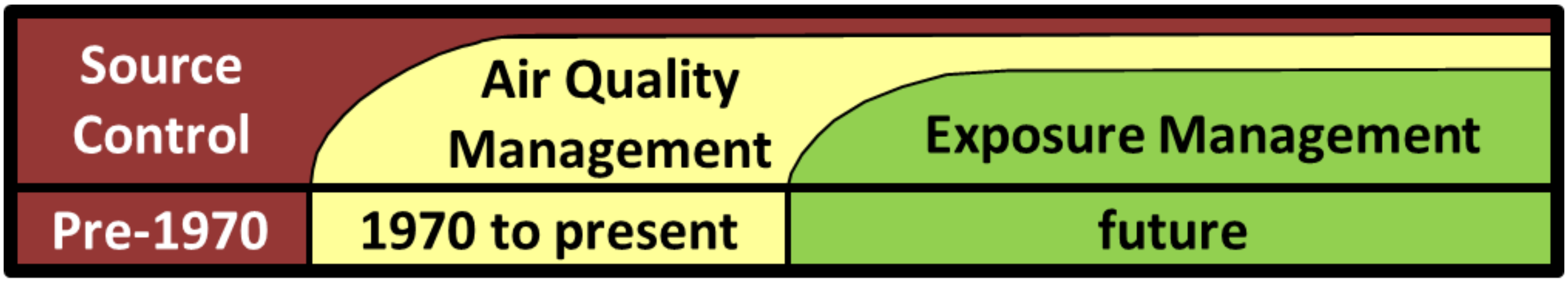
- The daily E_a/C ratio is not the same for everyone, but differs widely among individuals by a factor of 2.5 over a 95% frequency range.
- NYC example from Jiao and Frey (2013), presented at Society for Risk Analysis annual meeting, using a stochastic population-based exposure model

Exposure Assessment Vision

- Development of an *integrated systems approach* to exposure science
- Better address scientific, regulatory, and societal challenges
- Provide exposure information to a larger population

NRC (2012)

Moving Toward a New Paradigm



- **Source control**: ineffective at improving air quality (e.g., ozone, particulate matter)
- **Air quality management**: ineffective at preventing high end exposures to sensitive populations
- **Exposure management**: there are more ways to manage exposure beyond managing air quality

Discussion

- Exposure Science is developing in several areas:
  - Measurement of activity
  - Measurement of microenvironmental concentration
  - Modeling methods and tools
- Exposure assessment has become accepted as an integral part of reviewing and revising the U.S. NAAQS
- However, there is an opportunity to shift from air quality management to a broader approach based on exposure management
- Emerging technologies and techniques enable development of exposure assessments based on site-specific data