Equilibrium Environmental Inc.

WATERTECH 2011

ASSSESSMENT OF SHOWER EXPOSURES – NEW HEALTH CANADA PATHWAY FOR GUIDELINE DEVELOPMENT – CASE STUDY WITH BENZENE SOURCED FROM GROUNDWATER

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Background

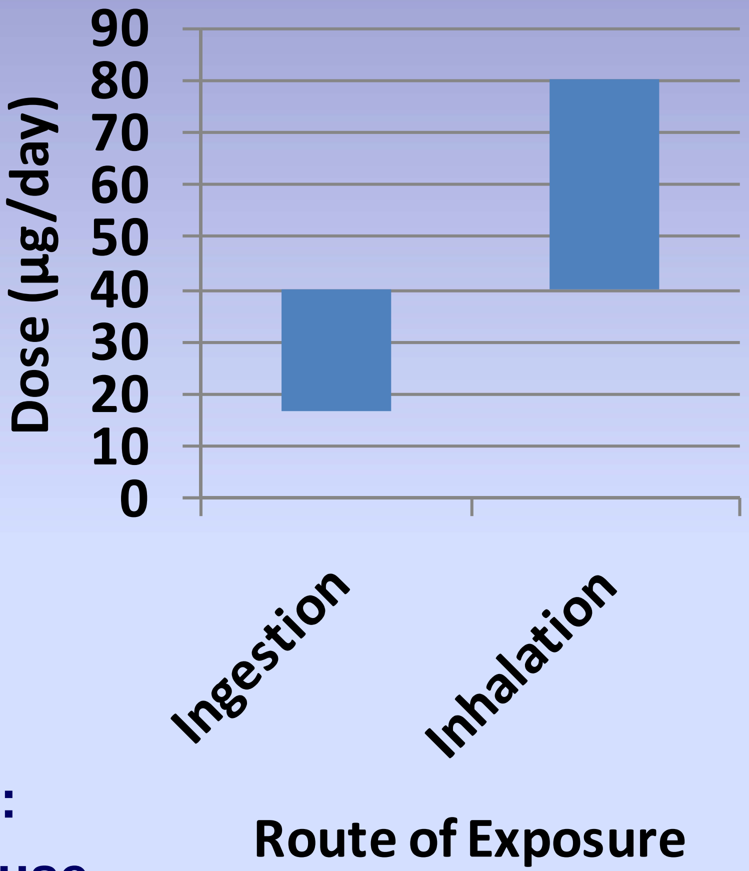
- Benzene Drinking Water Guideline (DWG)
  - based on drinking water exposure (1.5 L/day consumption)

- Health Canada included showering exposures for a proposed update to the benzene DWG based on,
  - Benzene likely to cause similar effects in humans regardless of route
  - Showering contributes
    - » 1.7 & 0.88 L/day equivalent exposure via inhalation & dermal
  - Proposed change in DWG from 5 to 1 µg/L

- Issues
  - HC approach used a generic screening shower model
  - may not be appropriate to assess inhalation exposures against the drinking water standard
  - Current tox data for the oral limit may not be the best

History of Shower Exposures

- Late 1980’s chloroform exposure in the shower
- (Pellizari et al., 1987; Wallace 1987)
  - ~50% of mass in water volatilizes
  - 40 to 80 µg/day via inhalation
  - 17 to 40 µg/day via ingestion
  - inhalation exposure is important
  - contribution will vary by chemical



- Experimental shower for testing
- Model development
  - McKone, 1987; three compartments:
  - shower, rest of bathroom, rest of house
    - some reasonable model fits to measured data for chloroform
- People now looking at the influence of dishwashers...

History

- Shower exposures examined for other volatile substances
- Radon
  - areas naturally high in radon, water well sources
- Trichloroethylene
  - dry cleaner groundwater impacts, water well sources
- Methyl tertiary butyl ether (MTBE)
  - gasoline additive, water well sources (municipal in the case of Santa Monica)
- Benzene
  - gasoline impacts from gas stations, water well sources

History

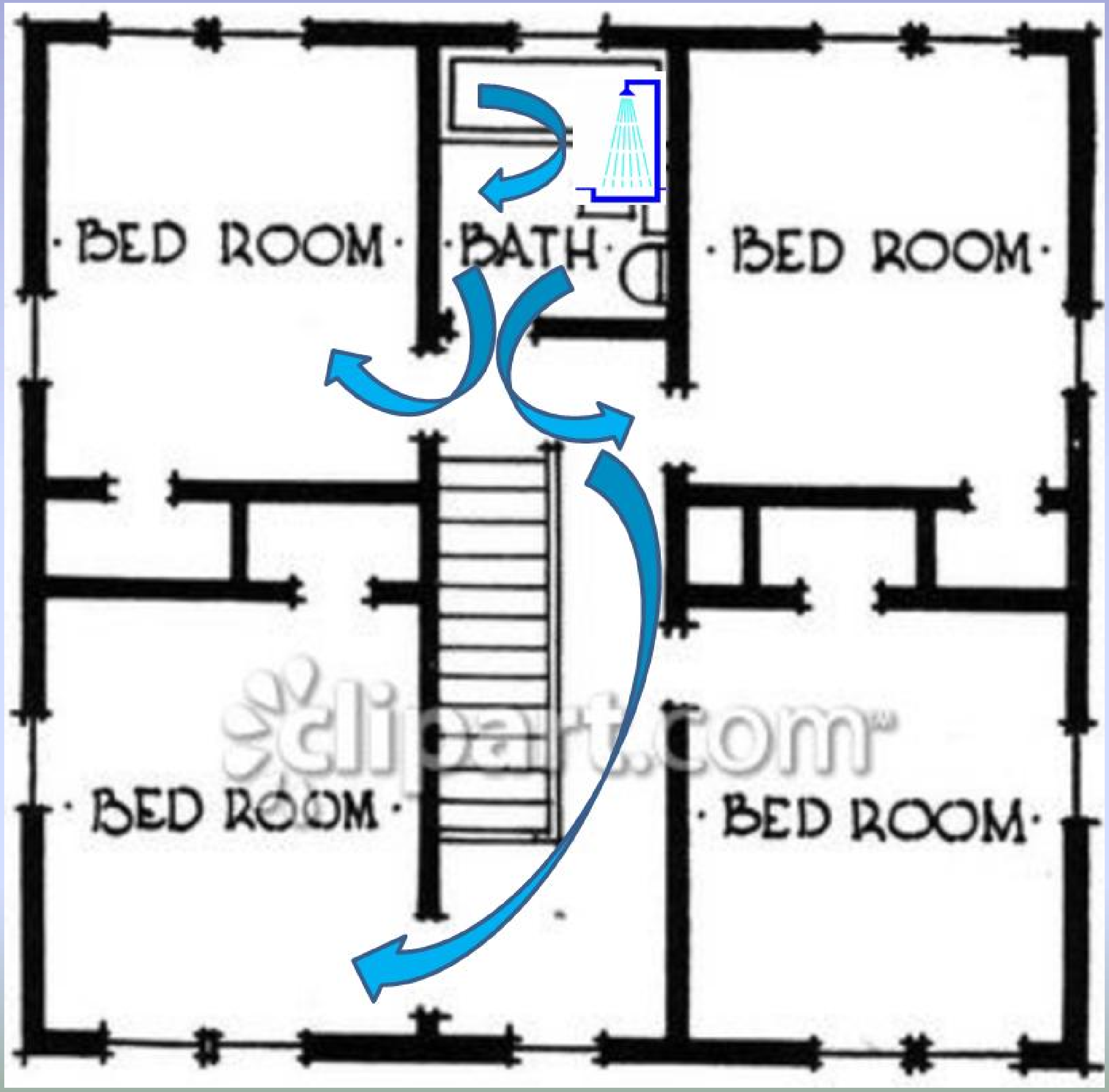
- **In addition to inhalation...**

- **Attempts made to determine whether dermal exposure was important**
  - volunteers exposed to chloroform in shower water
  - chloroform exhaled in breath was measured
  - with and without wetsuits
  - dermal exposure was found to be equivalent to inhalation

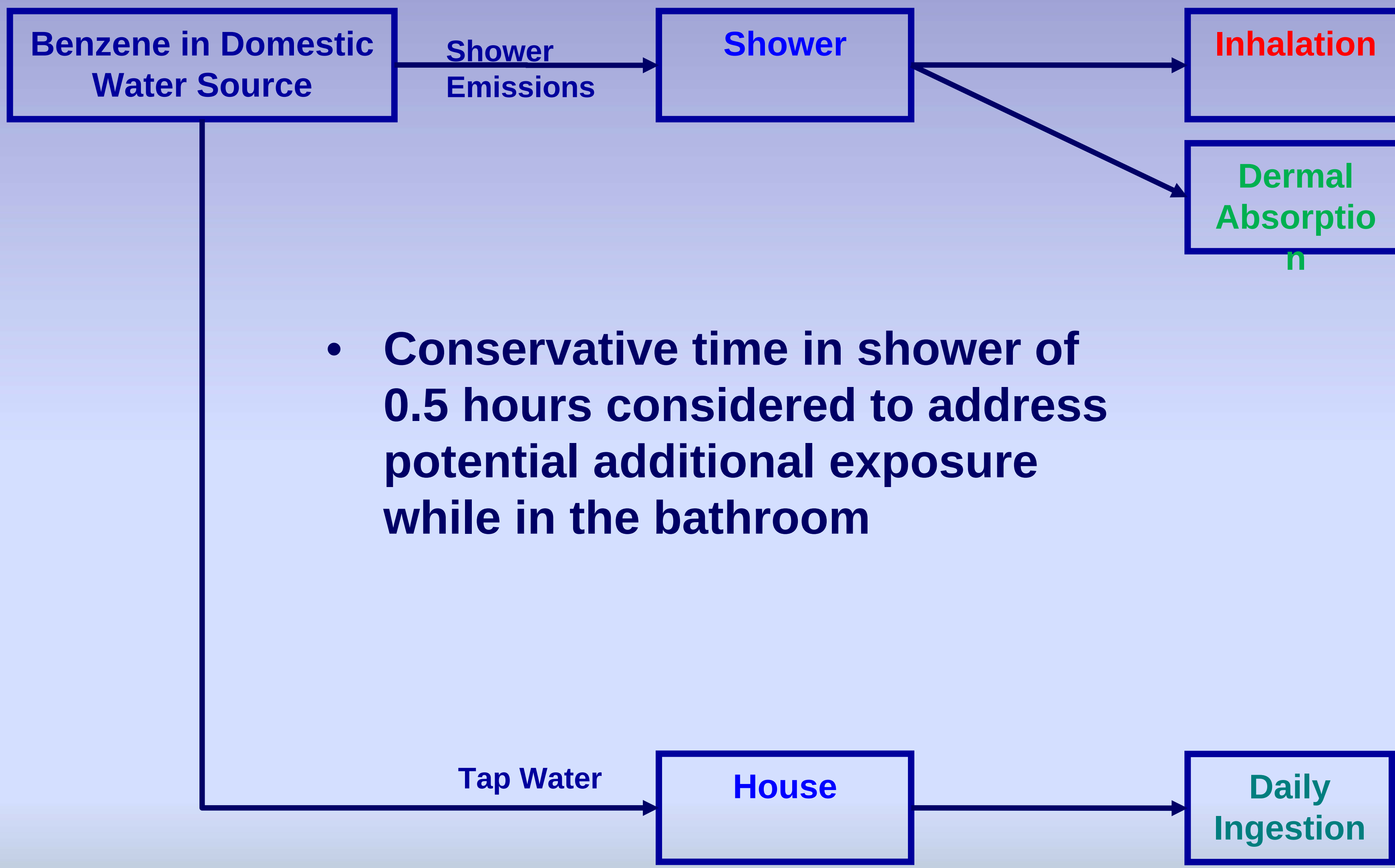
- **Results indicate integrated exposure need to be considered for,**
  - ingestion
  - inhalation
  - dermal

How are Shower Exposures Estimated?

- hot water containing volatile compounds
- estimate air concentration
  - shower stall, bath, rest of house
- estimate inhaled dose
- skin contact – estimate dermal dose

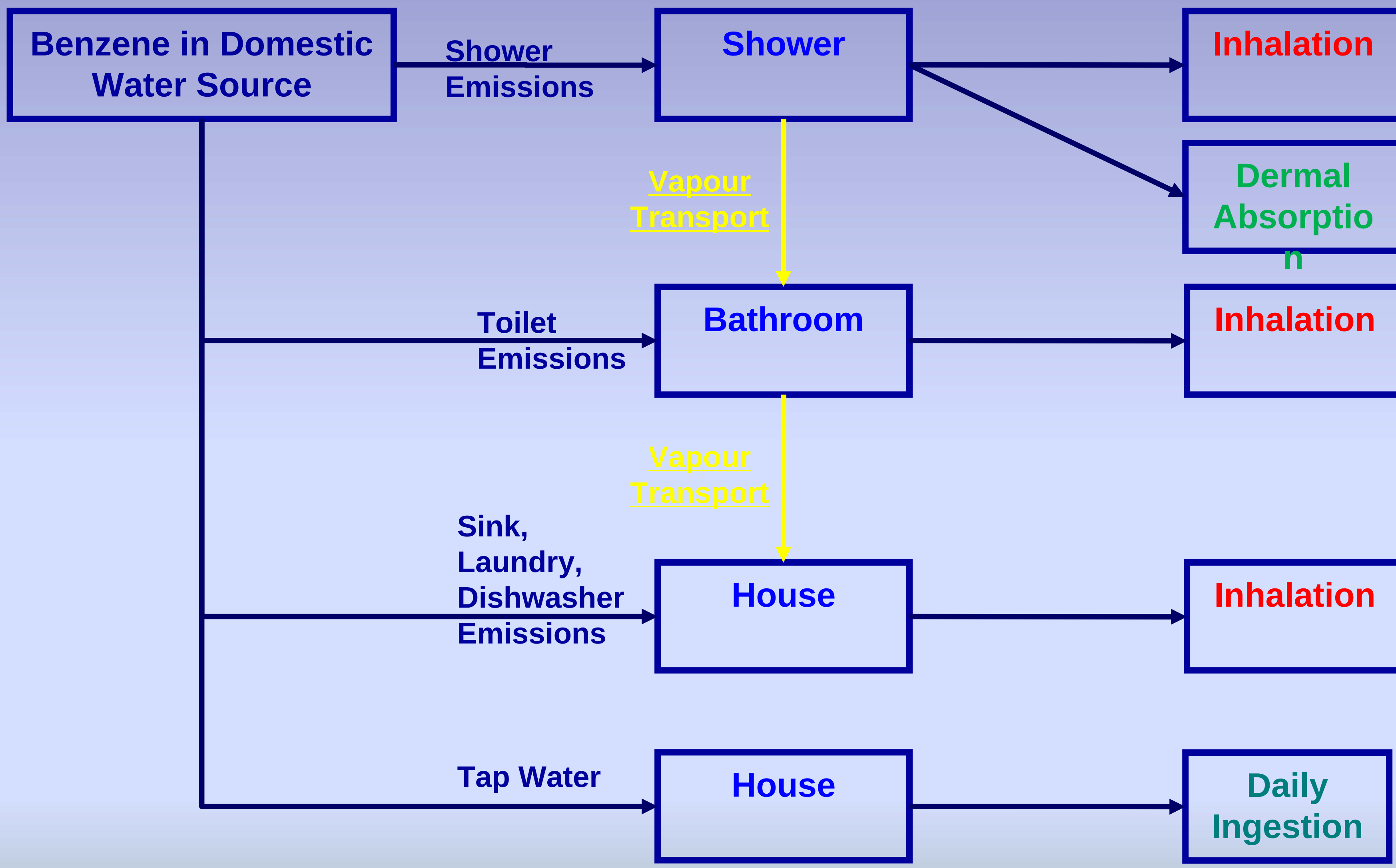


Model Construction – Health Canada



- Conservative time in shower of 0.5 hours considered to address potential additional exposure while in the bathroom

Model Construction – This Project



- Shower, bathroom, & house emissions addressed quantitatively

Model Construction

– **Sensitive Variables**
  - **Water use levels**
  - **Emission rates from different water uses**
  - **Shower flow rate**
  - **Presence or absence of a bathroom fan**
  - **Showering time and time in bathroom**

– **Solve partial differential equations using du/dt substitutions**
  - **Shower**

$$\frac{dC_S}{dt} \cdot V_S = \left[Q_S \cdot C_W \cdot TE_S\right] - \left[Q_S\left(C_S(t) - C_B(t)\right)\right]$$

  - **Bathroom**

$$\frac{dC_{BT}}{dt} \cdot V_{BT} = \left[Q_T \cdot C_W \cdot TE_T\right] - \left[Q_{BT} \cdot C_{BT}(t)\right] - \left[Q_S\left(C_{BT}(t) - C_S(t)\right)\right]$$

  - **House**

$$\frac{dC_{HT}}{dt} = \frac{Q_{HW} \cdot C_W \cdot TE_H}{V_H} + \frac{Q_{BT} \cdot C_{BT}(t)}{V_H} - \frac{Q_H}{V_H} \cdot C_H(t)$$

Model Parameters

- Model parameters developed
- Key differences include:
- 10 versus 20 min shower
- More specific building parameters
- Hot and cold water temperature for different uses
- Shower frequency
- Household water use for a family of 4
- Water flow rate

Parameter Name	Units	Value min	Value MLE	Value Max	Reference
Shower water flow	L/min	8.7	10	11.4	Jo et al 1990 a,b; in Chowd 2009
	L/min	4.9	8	12.9	US EPA, 1997
Shower stall volume	m^3	1.67	2	2.25	Jo et al 1990 a,b; in Chowd 2009
Bathroom volume	m^3	5	10	50	McKone, 1989 (estimated)
Building volume	m^3		535.8		AENV, 2008 (12.2 x 12.2 x 3.6)
Shower air exchange rate	Ach/hr		12		
Bathroom air exchange rate	Ach/hr		3		
Building ventilation rate	Ach/hr		0.5		(AENV, 2008)
Shower time	min/shwr	5	10	20	McKone, 1987
	min/shwr		10.4		US EPA, 1997
Time in bathroom after shower	Min		20		McKone and Knezovich, 1991
Hot water temperature	C	35	40	45	Chowdhury (in press); in Chowd 2009
Cold water temperature	C	15	20	25	Chowdhury (in press); in Chowd 2009
Shower frequency	shwr/day	0.72	0.74	0.76	US EPA (1997)
Area of exposed skin to shower water	m^2	1.69	1.82	1.94	Health Canada, 1997
Toilet water use (n=family of 4)	L/day		68.4 x 4		US EPA (1997)
Dishwasher & Laundry (n=family of 4)	L/day		72.2 x 4		US EPA (1997)
Kitchen sink and cleaning use (n=4)	L/day		19 x 4		US EPA (1997)

Model Calibration

- Lindstrom *et al.* (1994)
  - A key supporting study for shower-related benzene exposure
  - residence with benzene contaminated groundwater
    - Mean benzene water concentration – 296 µg/L ~ 60x DWG
  - No bathroom fan
  - Residence with a relatively low air exchange rate
    - (0.35 Ach/hr)
  - Shower run for 20 minutes
  - Measured transfer efficiency
    - Benzene in water: shower head – floor drain; mean of 0.88

Model Calibration – Lindstrom Data

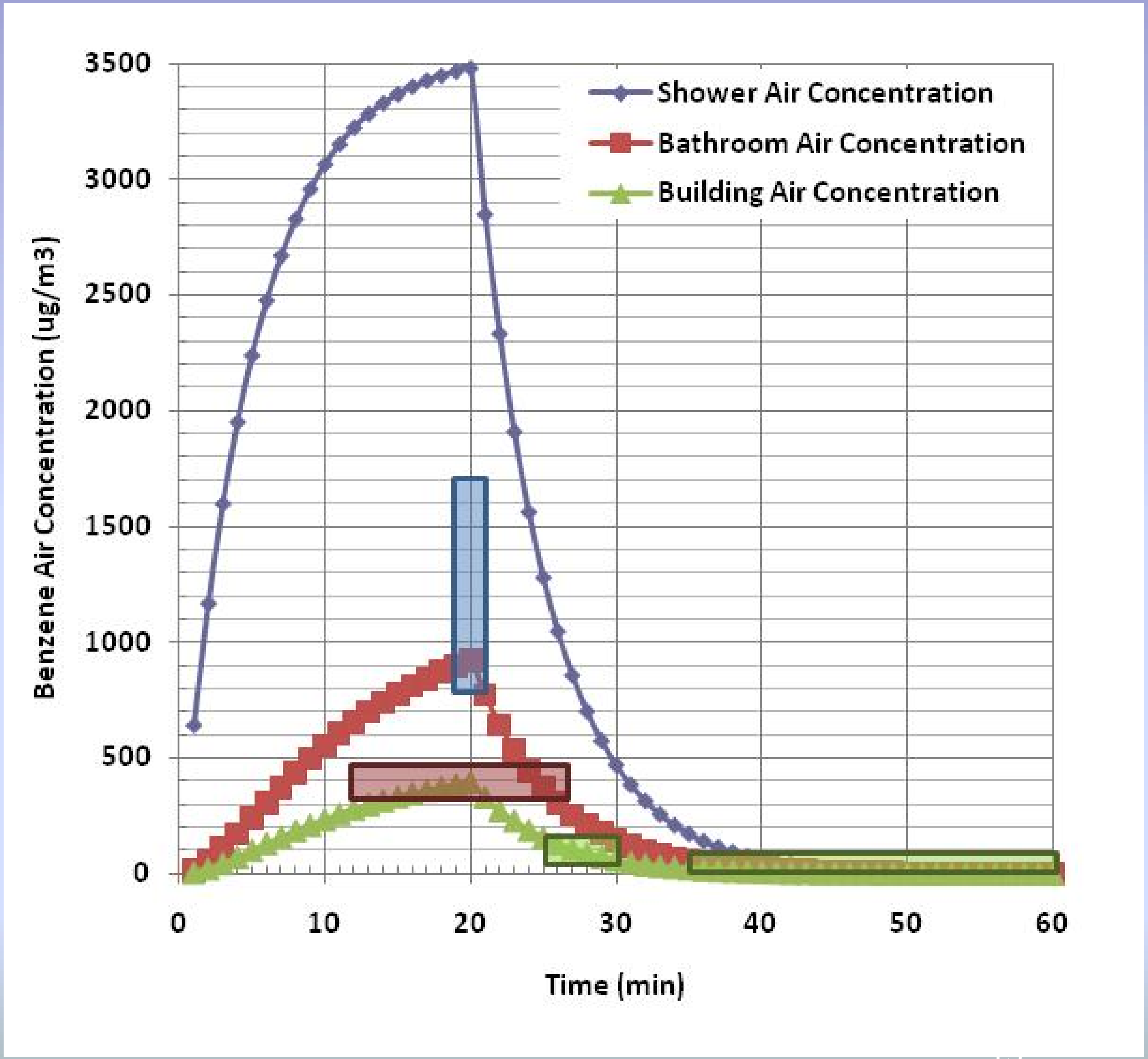
- Shower emissions only

- **Blue Bar**
- Measured Shower air concentrations over time interval

- **Red Bar**
- Measured Bathroom air concentrations over time interval

- **Green Bars**
- Measured Bedroom & House air concentrations over time interval

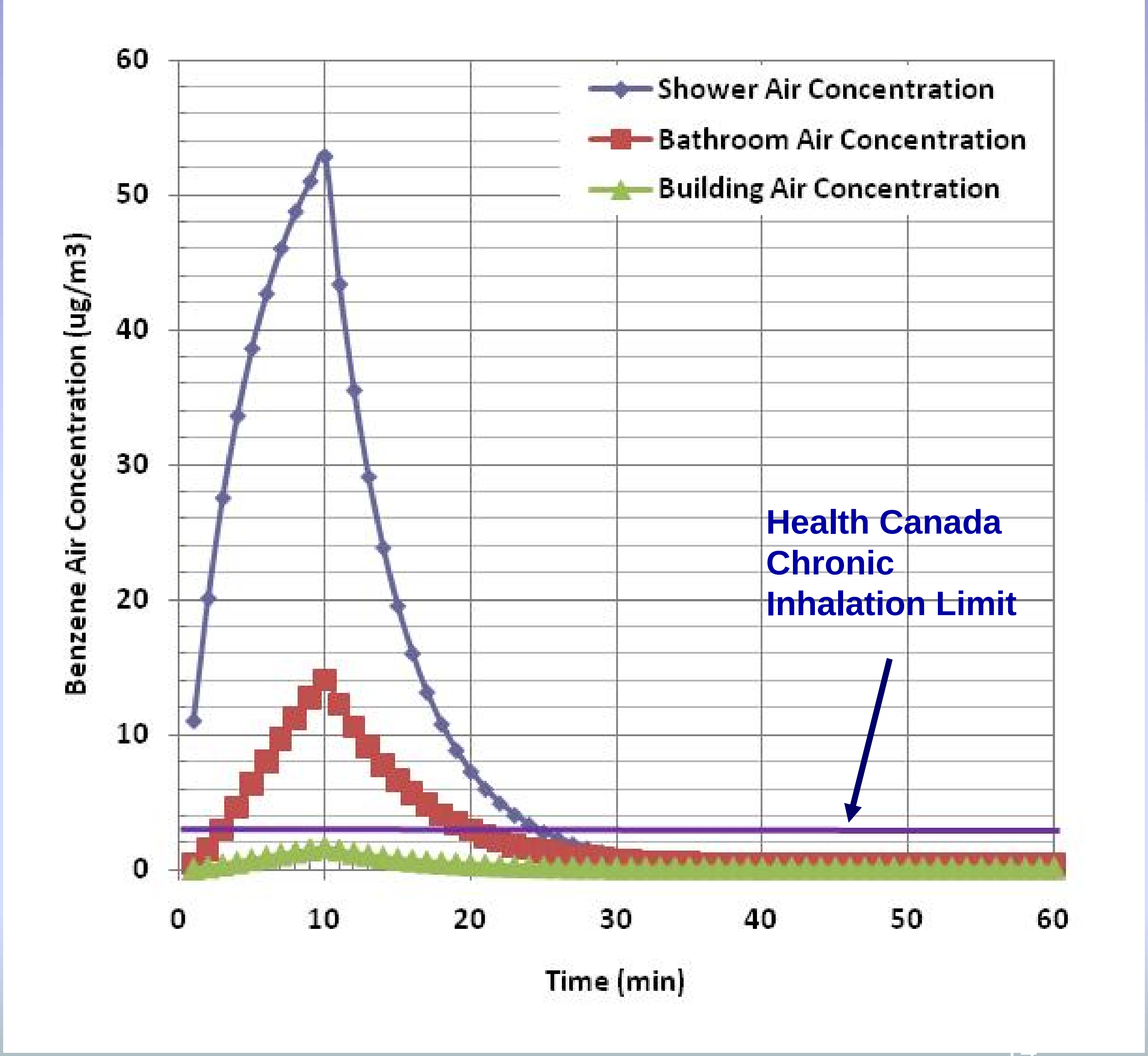
- Shower and bathroom
- ~2x over-prediction
- Bedroom – in range
- House – under-prediction



Modeling for Guideline Development

- **Water Concentration**
  - **0.005 mg/L (5 µg/L)**

- **Chronic inhalation limit not exceeded for times in the house after showering and in the bathroom**



Preliminary Inhalation Doses

Exposure	Amortized Air Conc.	Absorbed Dose	Dose Ratio	HC Ratio
	mg/cu.m	mg/kg-d	Inh/Oral	
Shower - Inhalation	1.5E-04	1.6E-05	0.16	- -
Bathroom - Inhalation	1.1E-05	1.1E-06	0.01	- -
House - Inhalation	1.5E-04	1.6E-05	0.15	- -
Sum - Inhalation	**3.1E-04**	**3.2E-05**	**0.32**	**1.75**

- **Reasons for differences versus HC Ratio**
  - Showering intervals and duration per day
  - Bioavailability
  - Building parameters
  - More refined model

Preliminary Dermal Doses

$$DAD = \left(\frac{Cw \cdot SA \cdot Kp \cdot t \cdot F \cdot (1 - TE)}{BW} \right)$$

DAD = Dermally Absorbed Dose (mg/kg-day)

TE = transfer efficiency for benzene volatilization in the shower (0.88; Lindstrom et al., 1994) (OR, take average (1, 0.88) = 0.56)

Cw = concentration in shower water (ug/L) (5 ug/L = AENV DWG for benzene)

SA = skin surface area (cm^2) (18,200 cm^2; or 1.82 m^2)

Kp = permeability coefficient (m/min) (3.5E-5 m/min or 0.21 cm/hr)

t = time of event (min) (10 minutes shower)

F = frequency of showers (events/day) (0.74 showers/day; US EPA, 1997)

BW = body weight

Exposure	Absorbed Dose	Dose Ratio	HC Ratio
	mg/kg-d	Derm/Oral	Derm/Oral
Shower - Dermal	1.72E-05	0.17	0.88
Drinking Water - Oral	**1.02E-04**	1.00	

Rationale for Differences: dermal absorption, consideration of volatilization loss of benzene in water (using average of head/drain concentration), 10 minute actual shower time not 30 minutes used by HC

PBPK Modeling of Benzene

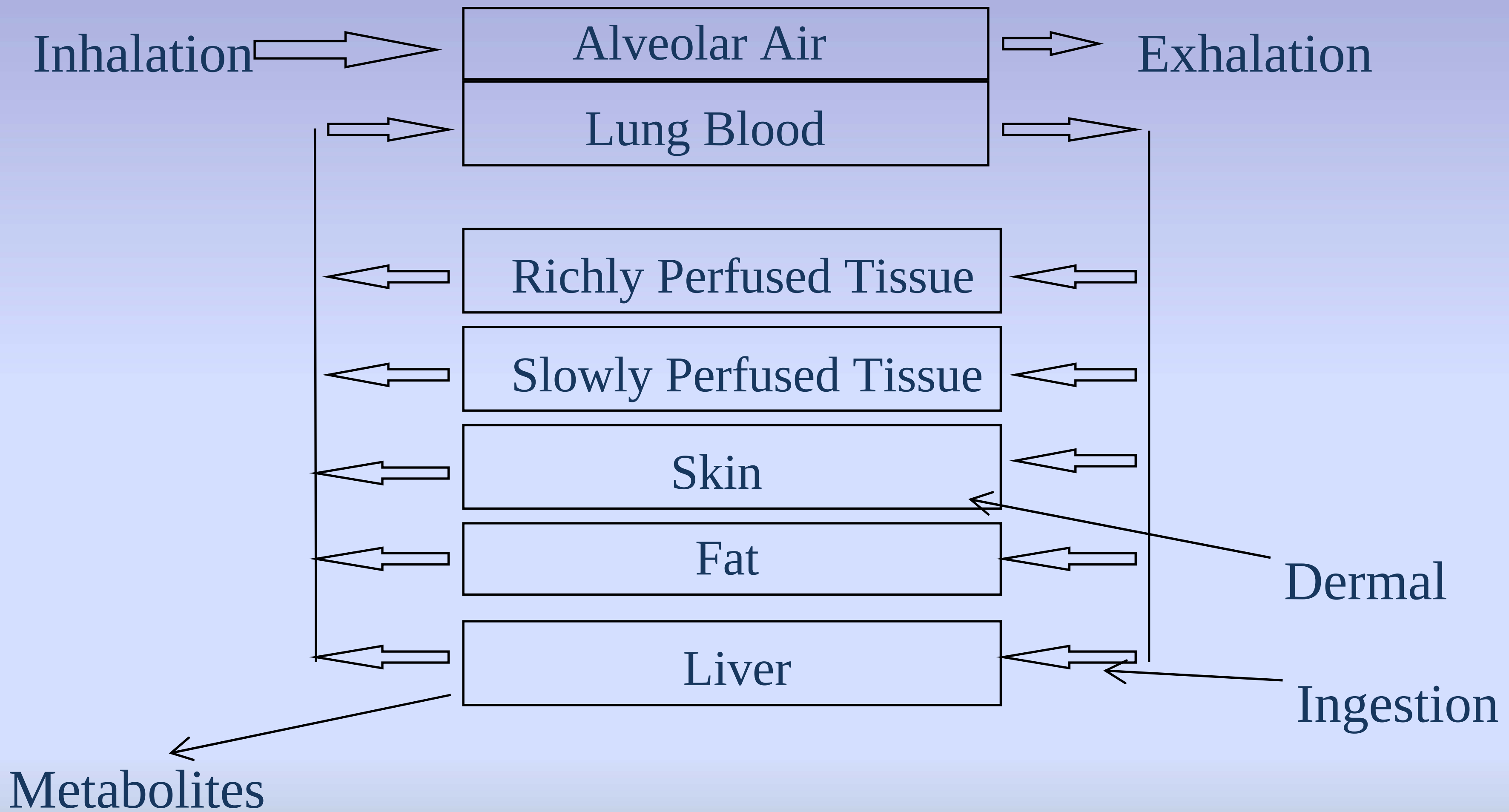
What We Know About Benzene

- Hematopoetic effects require metabolism to occur
- Hematopoetic effects are not likely dependent upon route of exposure (inhalation, oral, dermal)
- Kinetics (absorption, distribution, metabolism and excretion) of benzene in humans have been well studied
- Numerous physiologically based pharmacokinetic (PBPK) models have been developed for benzene
- Absorbed dose (or some measure of it) has been used extensively by regulatory agencies to conduct route-to-route extrapolation

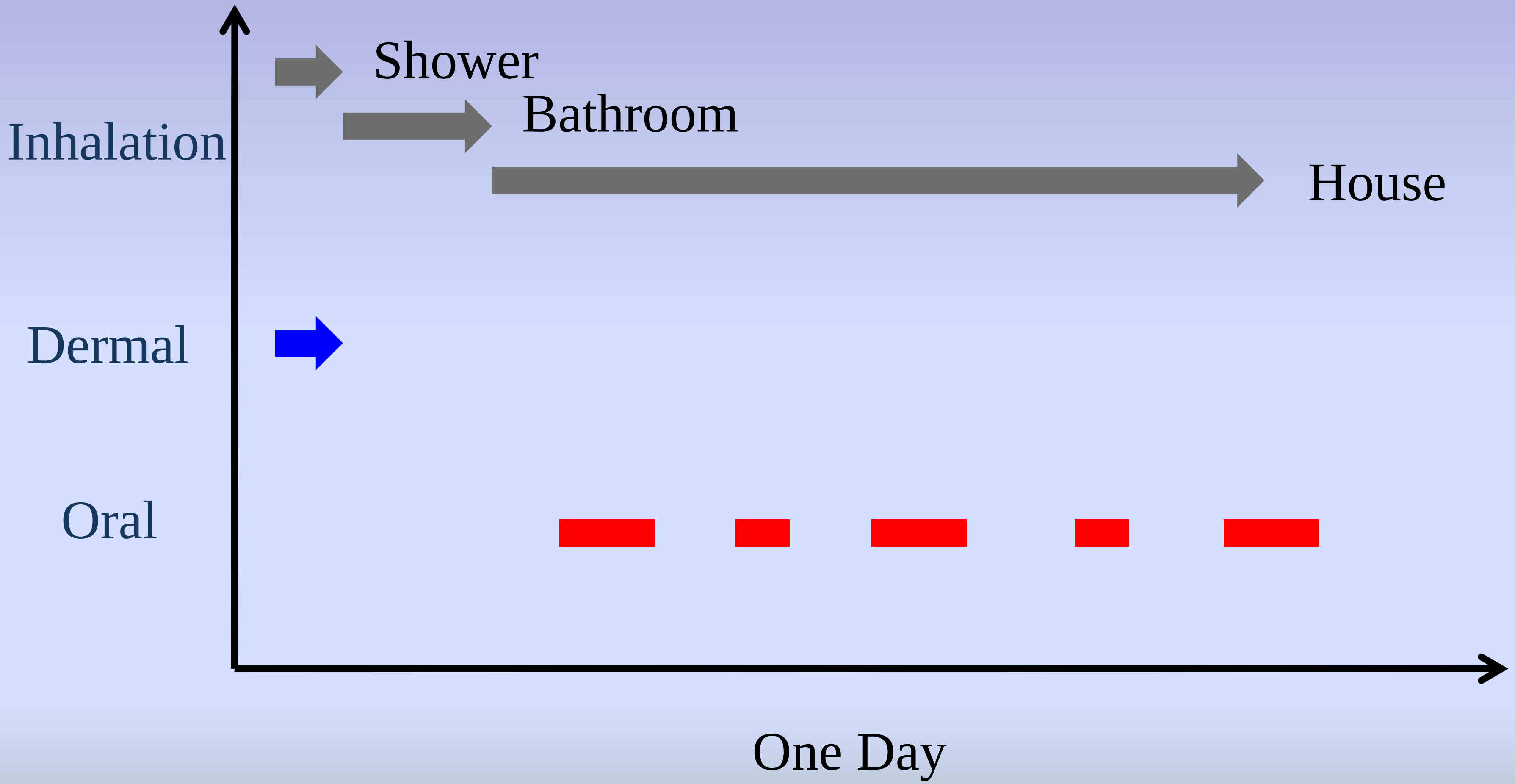
Objective

- Model the kinetics of multi-media/multi-route exposures to benzene to estimate key dose metrics (benzene in blood or amount metabolized) in humans associated with shower and in-home exposures
- Compare to inhalation guideline for benzene
- Assess the validity of Health Canada drinking water guideline

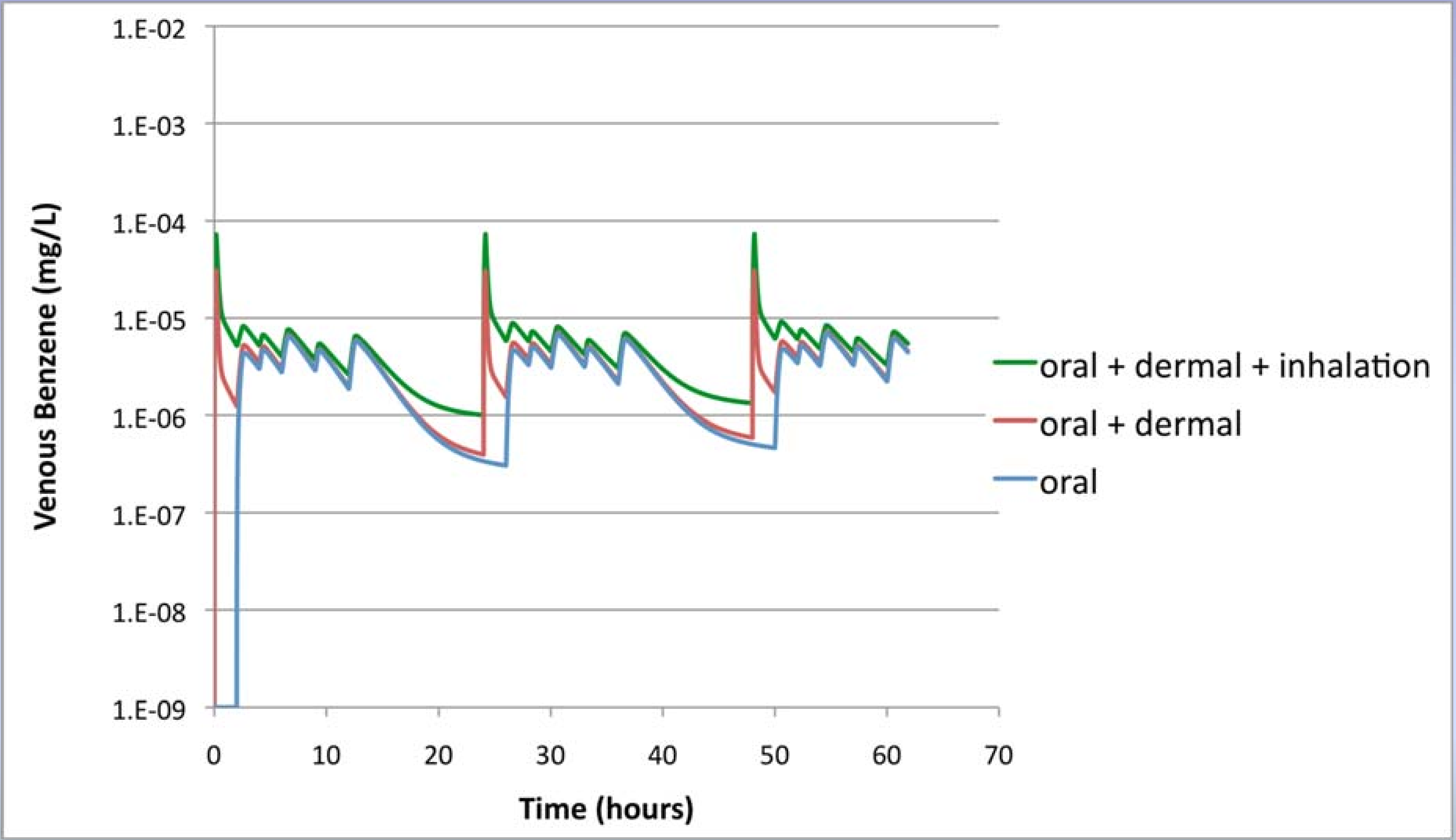
Benzene PBPK Model



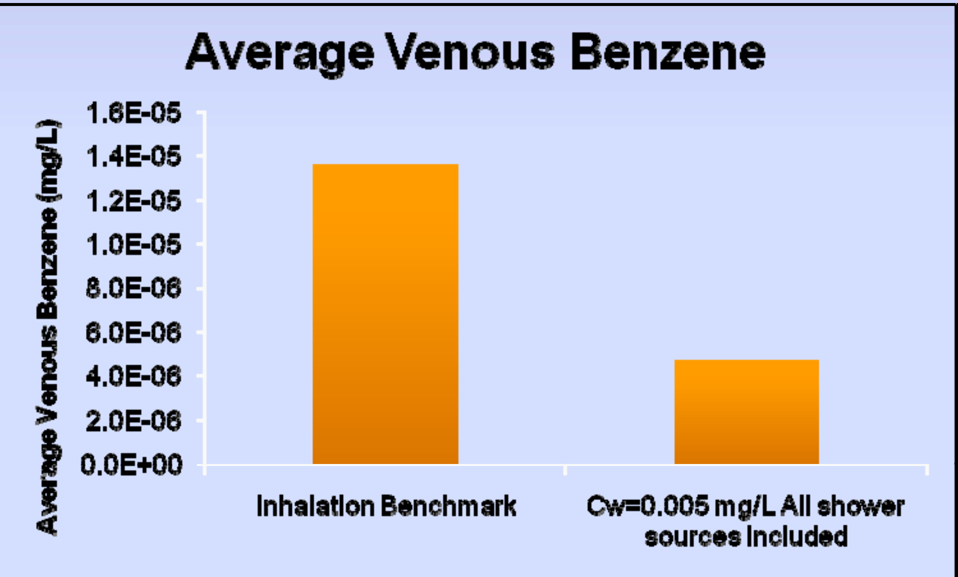
Exposure Scenarios

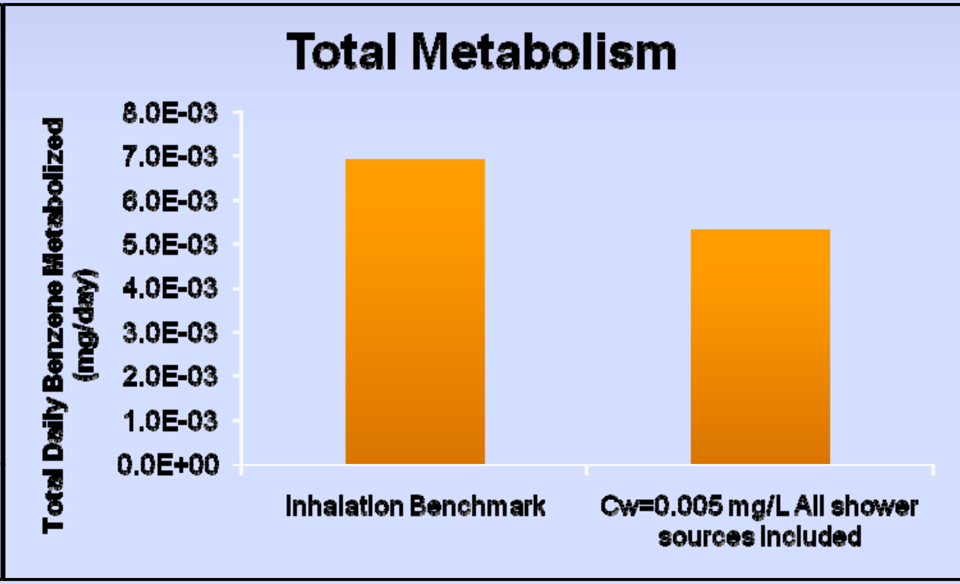


Model Simulations

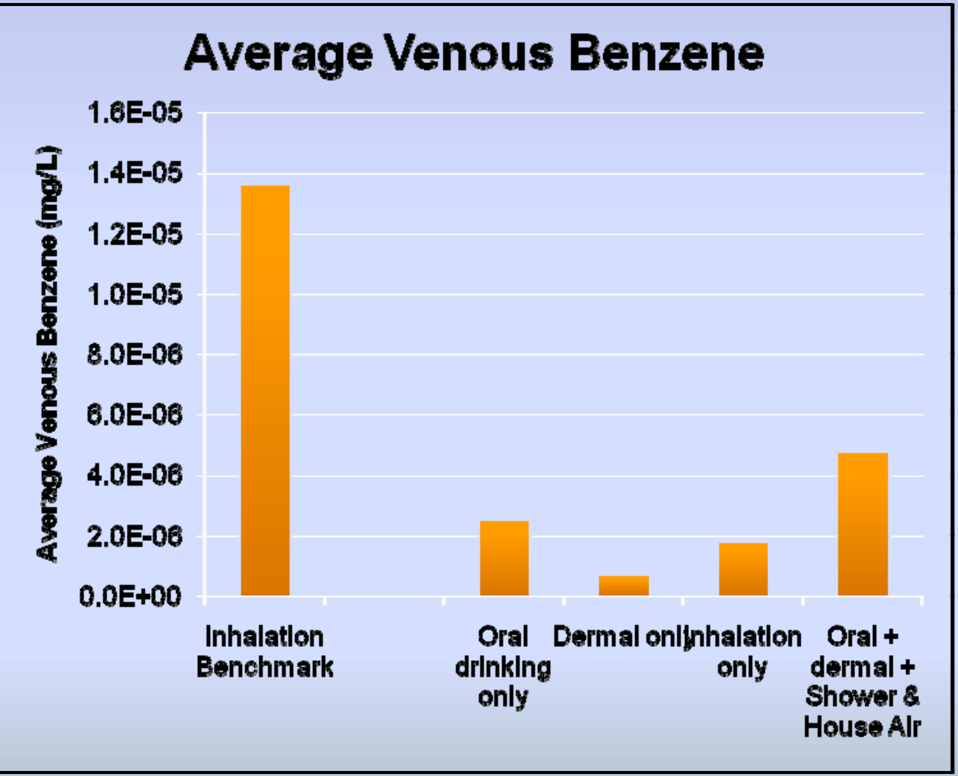


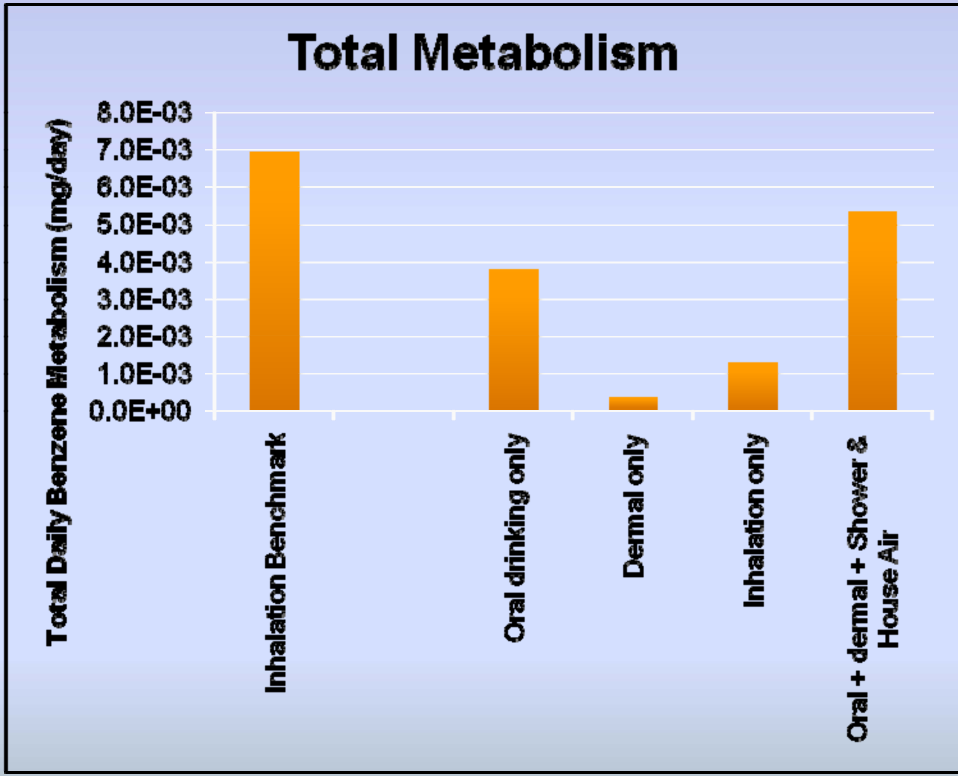
Dose Metrics From Shower Scenario (0.005 mg/L)





Dose Metric by Source





Conclusions

- Modeling benzene specific kinetics associated with home water supply exposure) was used to assess risk via water exposures
- Refined shower model coupled with a PBPK model suggests lowering of water standard is not necessary
  - DWG (0.005 mg/L) is sufficiently protective
- Toxicity data used to develop the drinking water standard may be overly conservative for assessing shower inhalation exposures