J. ENVIRONMENTAL SYSTEMS, Vol. 23(2) 179-194, 1994-95

COMPARING INDOOR AIR POLLUTION HEALTH RISKS IN INDIA AND THE UNITED STATES

J. S. PANDEY

S. MUDE

P. KHANNA

National Environmental Engineering Research Institute
Nehru Marg, Nagpur, India

ABSTRACT

Potential impacts of environmental pollutants on human health are evaluated on the basis of quantitative health risk assessment (HRA). Distribution, transport, human exposure, toxicology, and pharmacokinetics of pollutants are the principal element of health risk modeling. The usefulness of health risk assessment is dependent on knowledge of the possible exposure pathways and approaches available to model these exposures. In this article, cumulative human exposures (through inhalation, ingestion and dermal absorption) to volatile organic compounds have been estimated with a three-compartment model (shower, bathroom, rest of house). Results with United States data base reported in literature have been compared against those with estimated Indian data for volume of compartments and amount of water used.

INTRODUCTION

Potential impacts of environmental pollutants on human health can be estimated on the basis of quantitative health risk assessment (HRA) (see Figure 1). Distribution and transport of pollutants through air, water and soil; human exposure to the pollutant; and toxicology and pharmacokinetics of a pollutant in human beings are the elements involved in health modeling. The accuracy and thoroughness of health risk assessment depend on knowledge of possible exposure pathways and on the approaches available to model these exposures (see Figure 2). Systematic analysis of occupational exposure and health has its roots in pioneering work by

doi: 10.2190/1HP4-7L0T-277J-XD9B
http://baywood.com

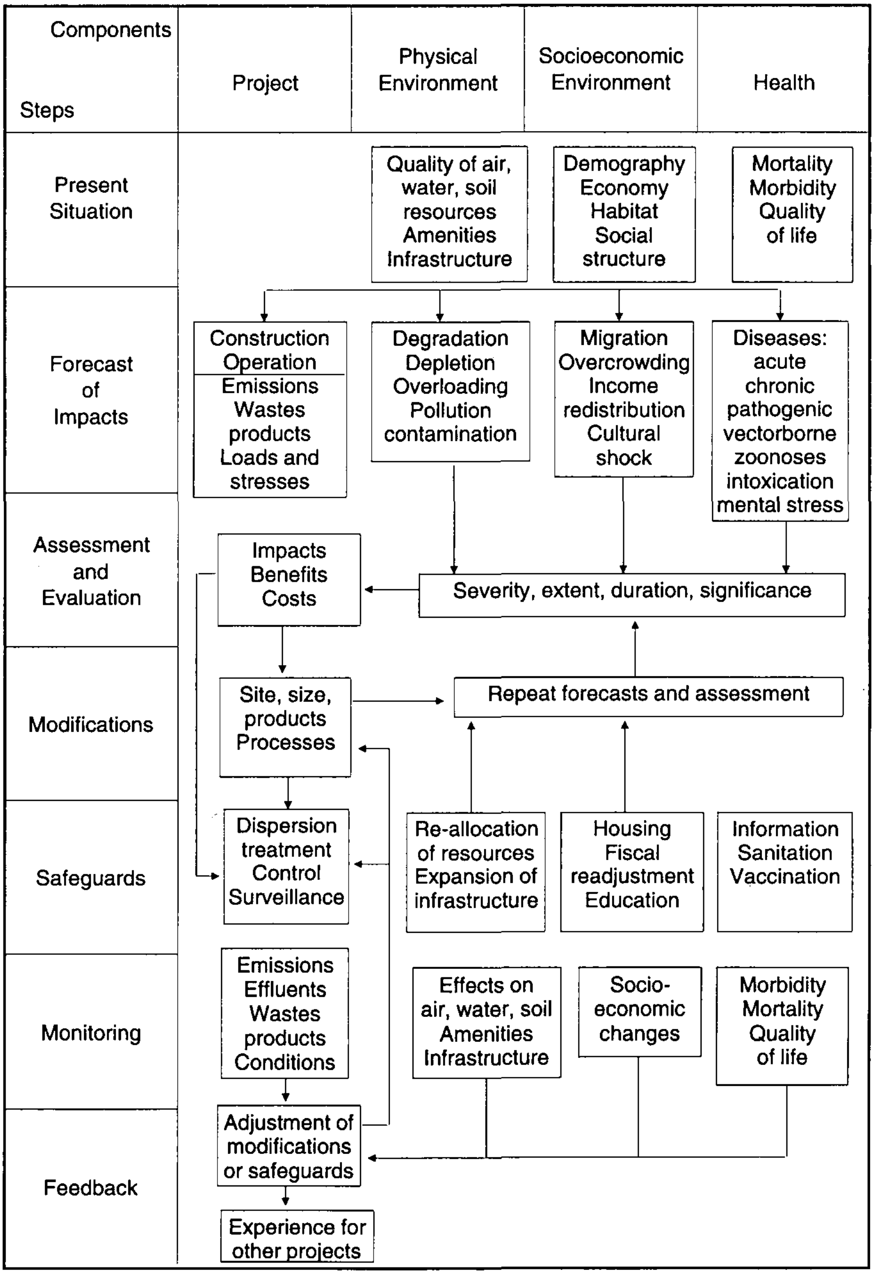

Figure 1. Environmental impact assessment process incorporating health component. Source: [19].

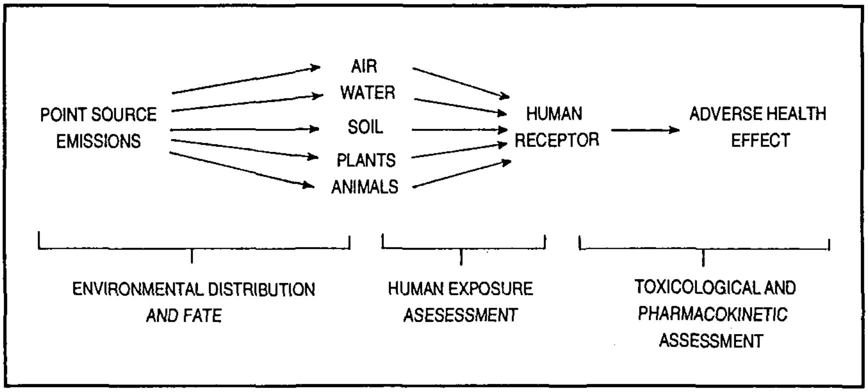

Figure 2. Environmental and toxicological fate of a chemical
Source: [20].

Alice Hamilton et al. [1]. After the potential sources of exposure to single or multiple chemicals are identified, the toxicity of the contaminants, the pathways and the intensity of exposure are identified and estimated in Hamilton's approach. First sets of workplace limits [1] were published on the basis of information available on toxicity, exposure, and human health effects of contaminants. The measurement strategies for exposure assessment have been evolving as more information has become available from personal monitoring and indoor and outdoor air quality measurements [2, 3]. USEPA has published comprehensive exposure assessment guidelines [4, 5].

Work on indoor air pollution in today's environment has brought out the difficulty in comparing health standards reflecting open ambient conditions with air quality levels prevailing inside enclosed areas. Indoor pollution problems also compound the uncertainties about air pollution effects.

In this article, cumulative human exposures (through inhalation, ingestion, and dermal absorption) to volatile organic compounds (VOCs) have been estimated by means of a three-compartment model [6]. Results based on American data have been compared against those based on estimated Indian data for volume of compartments and amount of water used.

VOC EMISSIONS AND HUMAN EXPOSURE

Air emission sources include landfills, surface impoundments, land treatment facilities, open tanks and containers, equipment leaks, transfer, storage, handling operations, and pollution control systems [6, 7]. Depending on the source, emissions can be classified into two basic categories: VOCs and particulate matter. VOCs are gaseous materials which consist of air toxic compounds, carcinogens, and ozone precursors, while particulate matter includes metals, aerosols and/or organics, and dust, including associated toxics and carcinogens.

VOC emissions can occur through a variety of mechanisms, including volatilization, biodegradation, photodecomposition, hydrolysis, and incineration. The importance of these mechanisms varies as a function of source type. Volatilization is often the most important mechanism for air emission and occurs when molecules of a dissolved compound escape to an adjacent gas layer. Volatilization can occur at a relatively low temperature, while vaporization (changing a liquid to gas phase by boiling) requires a much higher temperature.

Biodegradation takes place when microbes break down organic compounds for metabolic changes. It can be an important mechanism for gas phase emissions from landfills, surface impoundments, and land treatment facilities. The rate of organic decomposition depends on the structure of the compound, the metabolic requirements of the microbes, and site-specific environmental conditions. Photodecomposition occurs when a compound absorbs light and reacts, or when the compound reacts with water. For organic compounds, the reaction usually replaces a functional group with a hydroxyl. Incineration (thermal oxidation) of organic wastes can be a source of both particulate matter and gaseous pollutants, including volatile, semi-volatile, and almost non-volatile organic compounds.

Human exposure to volatile compounds in water can occur from pathways other than direct ingestion. These pathways include inhalation of contaminants transferred to the air from showers, baths, toilets, dishwashers, washing machines, and cooking; ingestion of contaminants in food; and dermal absorptions of contaminants while washing, bathing, and showering. These pathways have been considered to be potentially important for volatile organic compounds (VOC's) [8-10].

Quantification for exposure analysis requires development of measures of exposure and establishment of their relationships with biological effects. During the last decade, exposure assessments, which require a multidisciplinary team for technical and scientific analysis, have been conducted extensively.

The study must commence with the identification of the contaminants and their biological effects along with monitoring and modeling of various environmental media including air, water, and soil. The science of exposure is gradually evolving into a coherent quantitative discipline that gathers information from environmental, toxicological and health studies, as well as from its own basic and applied experiments.

Tracing the movement from the source of a pollutant to its proximate or ultimate effect is fundamental to any exposure-dose-effect investigation based on a single route (see Figure 3). Total exposure is estimated as an aggregate of contributions from multiple routes. Contributions from each route may be additive or synergistic in terms of exposure-dose-response relationship. Significant human exposures are usually compared on the basis of the dose derived from contact with each medium [11-13].

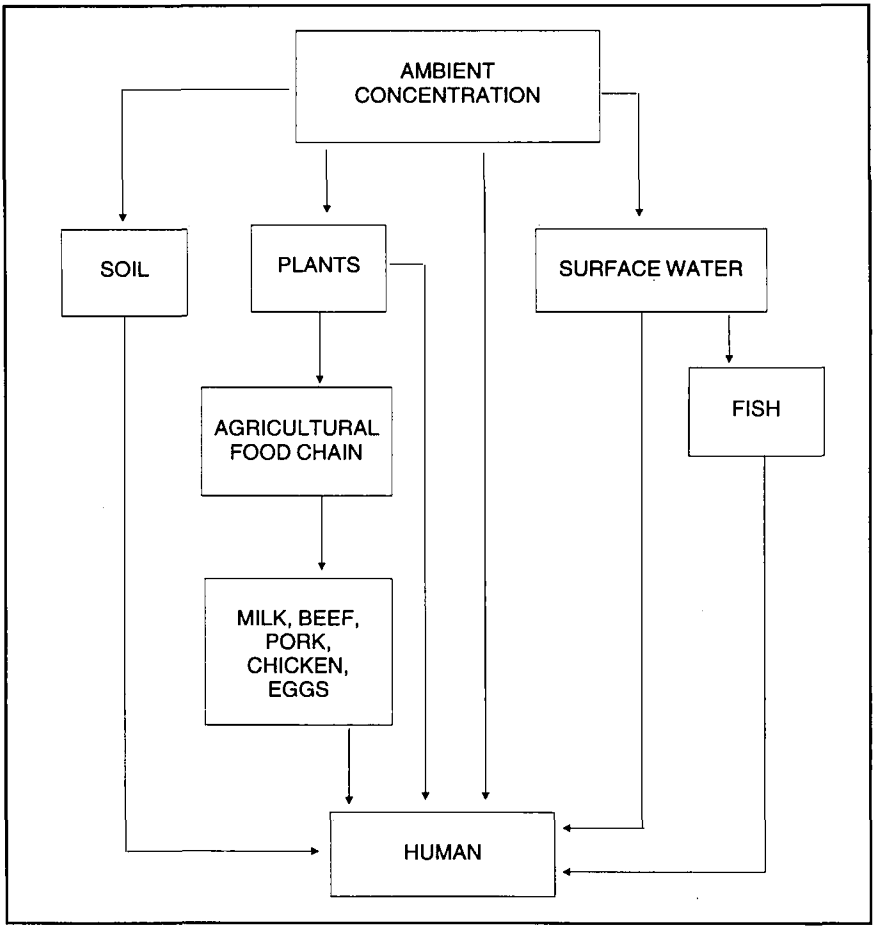

Figure 3. Environmental fate pathways and exposure routes in a multimedia health risk assessment. Source: [20].

Exposure studies are designed to identify a specific population at risk, define norms for the population at large, and examine long-term effects of the reduction or increase of exposure to a contaminant by monitoring selected groups or the general population.

ANALYSIS METHODOLOGY

An individual's exposure to a contaminant is defined as the contact at one or more boundaries (e.g., mouth and skin) between a human being and a *contaminant(s) at a specific concentration(s) for a period of time.* Total exposure includes contributions from all media (soil, water, food, air, plants) that contain a contaminant and all pathways of entry (inhalation, ingestion, dermal).

Mathematically, exposure is defined as:

$$E = \int_{t_1}^{t_2} C\,(t)\,dt \tag{1}$$

where E is exposure and C(t) denotes concentration.

The dose rate is estimated, for a 24 hour period, as:

$$D = (a*Br/Bw) \int_{0}^{24} C(t)*Of(t)\,dt \tag{2}$$

where,

a = fraction of air inhaled
Br = breathing rate (age-specific)
Bw = body weight (age-specific)
Of (t) = Occupancy factor

In most of the research attempts to estimate total exposure of an individual to a single contaminant, studies have been either confined to a subcategory of the available pathways or have been conducted for a limited period of time [14-18]. In order to estimate total exposure, data should be gathered for all significant environmental components and pathways of entry. Through personal measurements and modeling studies, the data can be generated to estimate the intensity and duration of exposure, and to assess its relationship with known health effects.

THE MODEL

The three compartments considered are shower, bathroom and remaining household (Figure 4). In respect of volume of different compartments and amount of water used, U.S. data significantly differs from Indian counterpart (Table 1). This leads to quite different scenarios for Indian conditions.

On the compartment model,

$$V_i \quad dC_i\,(t)/dt = Q_i(t) - \sum_j q_{ij}\,C_i(t) - q_{io}\,C_i + \sum_j q_{ij}\,C_j(t) \tag{3}$$

where

i = s(shower), b(bathroom), a(remaining household)
o = outside
$Q_i(t)$ = source terms (mg/min)

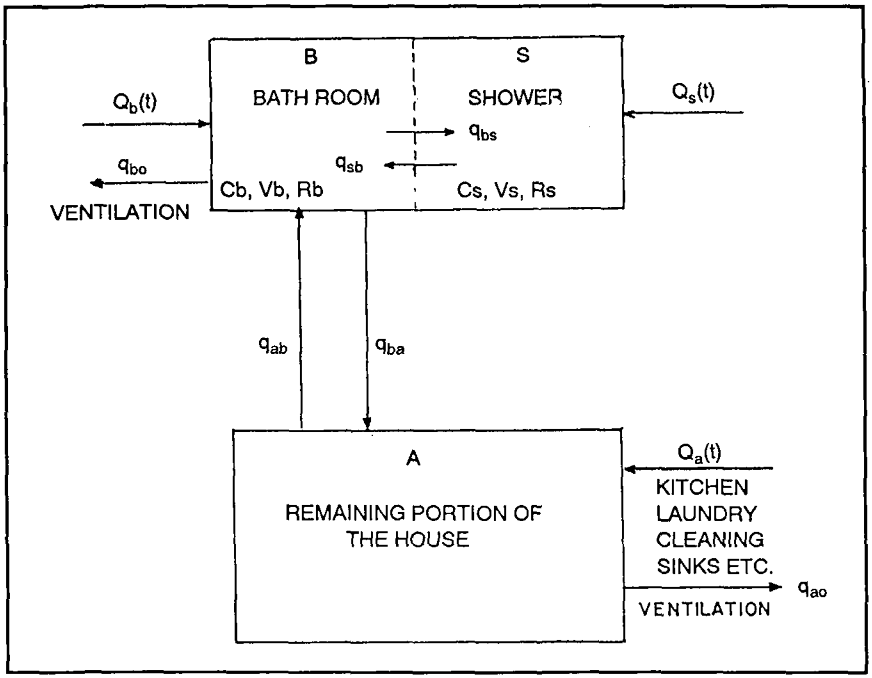

Figure 4. Three compartment model for VOC exposure analysis.

Table 1. Difference between U.S. Data and Indian Counterpart in Volume of Different Compartments and Amount of Water Used

Description	U.S. Dwelling	Indian Dwelling
1. Volume of Shower (Vs)	2000L	5000L
2. Residence time of air in Shower stall (Rs)	20 min	20 min
3. Volume of Bathroom (Vb)	10,000L	7070L
4. Residence time of air in bathroom (Rb)	30 min	30 min
5. Volume of remaining house (Va)	400,000L	226,000L
6. Residence time of household air (Ra)	120 min	120 min
7. Fraction of air leaving bathroom exhausted outdoors (f_o)	0.1	0.1
8. Water used in Showers and baths	300L	200L
9. Water used in toilets	300L	300L
10. Water for other household uses	400L	400L

V_i = volumes (L)
q_{ij} = air exchange rates (L/min)
C_i = concentrations (mg/L)

Air exchange rates are as follows:

$q_{sb} = q_{bs} = Vs/Rs$
$q_{ab} = Vb/Rb$
$q_{bo} = f_o\, q_{ab}$
$q_{ba} = q_{ab}\,(1 - fo)$
$q_{ao} = (V_a/R_a) - q_{ab}$

where R_s, R_b and R_a are residence times of air volumes in the shower, bathroom, and household, and f_o is the fraction of air entering the bathroom that is exhausted directly to outside air by ventilation.

Source terms are given by:

$$Q_i(t) = [I_i\, F_i H(t,t_{i1},t_{i2})/(t_{i2} - t_{i1})]\, C_w \quad (4)$$

where $Q_i(t)$ = time-dependent source term in the ith compartment (mg/min).

$I_i(t)$ = total amount of water consumed by activities in compartment i (L)
F_i = efficiency for transfer (mg/L initial concentrations) of the chemical from water to air for water used in compartment

$$H(t,t_{i1},t_{i2}) = 1 \text{ if } t1 <= t <= t2 \quad (5)$$

$$= 0 \text{ (otherwise)}$$

t_{i1}, t_{i2} = times at which activities in compartment i begin and end, respectively
C_w = contaminant concentration in water supply

RESULTS

Duration and exact timings for use of different compartments are shown in Table 2. Table 3 presents body weight and breathing rates for adults, children, and infants. Adults, children and infants have been defined as those belonging to age group (16-70), age group (2-16) and age group (0-2) respectively. Occupancy factor and time have been depicted in Table 4.

Figures 5 and 6 represent the concentration profile (w.r.t. time) for twenty-four hours for U.S. values and Indian values respectively. Maximum concentration in case of shower is 470×10^{-4} (mg/L) for the United States, while it is approximately 200×10^{-4} (mg/L) for Indian conditions. This fact is attributable to the larger volume of shower considered for Indian conditions. Similarly, for other two compartments, maxima for Indian conditions are much lower than that for shower.

Products P(C, OF) of concentration (C) and occupancy factor (OF : probability that an individual is in a given compartment) for three compartments have been

Table 2. Duration and Exact Timings for Use of Different Compartments

Description	Symbols	Value
1. Time when Shower water use begins	(t_{s1})	7 a.m.
2. Time when Shower water use ends	(t_{s2})	7:40 a.m.
3. Time when toilet water use begins	(t_{b1})	12 a.m.
4. Time when toilet water use ends	(t_{b2})	12 a.m. (Next day)
5. Time when other household water use begins	(t_{a1})	7 a.m.
6. Time when other household water use ends	(t_{a2})	11 p.m.
7. Transfer efficiency from Shower water to air	F_s	0.7
8. Transfer efficiency from toilet water to air	F_b	0.3
9. Transfer efficiency from household water use to air	F_a	0.66

Table 3. Body Weight and Breathing Rates

Description	Symbol	Value
1. Adults (16-70 years)		
Body weight	BWa	67 kg
Breathing rate (av)	BRa	14.7 (L/min)
2. Children (2-16)		
Body weight	BWc	32 Kg
Breathing rate (av)	BRc	10.3 (L/min)
3. Infants (0-2)		
Body weight	BWi	8.5 Kg
Breathing rate (av)	BRi	1.8 (L/min)

plotted in Figures 7 through 9. Figure 10 presents doses for different age groups (D_a, D_c, D_i) with respect to amount of water used in shower. The variations in all three doses seem to be similar. Highest values of dose are observed for infants while the variations with respect to amount of water used in bathroom for children are most significant (Figure 11).

Changes in volumes of the compartment bring about such changes in dose values as are on the order of magnitudes different. Consequently, the values have been plotted in logarithmic scales (Figure 12). When the volumes of shower

Table 4. Occupancy Factor and Time

Description	Occupancy Factor[a]	Occupancy Time
1. Shower	0.25	7 a.m.-7:40 a.m.
	0.0	otherwise
2. Bathroom	0.16	7 a.m.-9:00 a.m.
	0.018	otherwise
3. Remaining household	1.0	24 p.m.-5 a.m.
	0.24	5 a.m.-22 p.m.
	1.0	22 p.m.-24 p.m.
4. Contaminant concentration in water supply (Cw)	1 (mg/Liter)	
5. Fraction of the chemical taken into the total lung volume that is available for uptake (x)	0.5	

[a]Occupancy factor is defined as the probability that an individual is in a given compartment at time t (unit less).

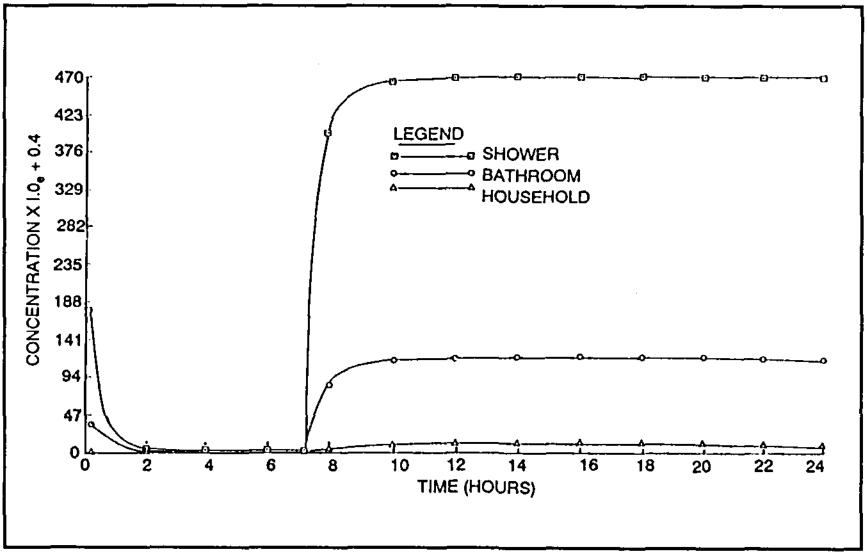

Figure 5. Reference values.

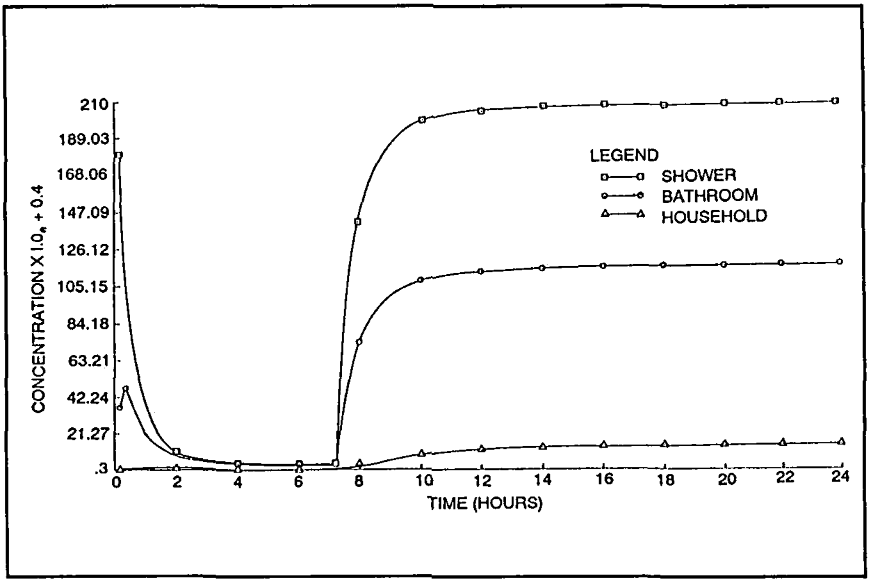

Figure 6. Values for the case study.

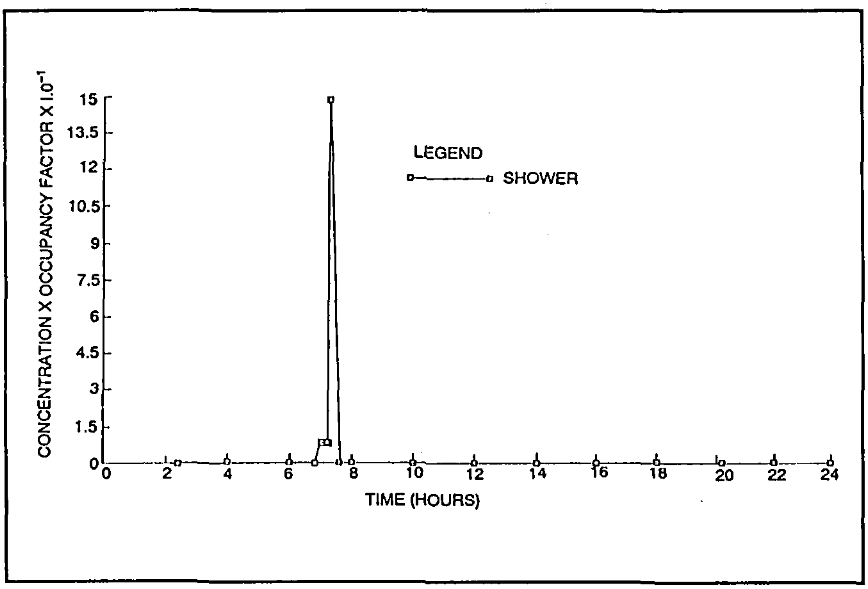

Figure 7.

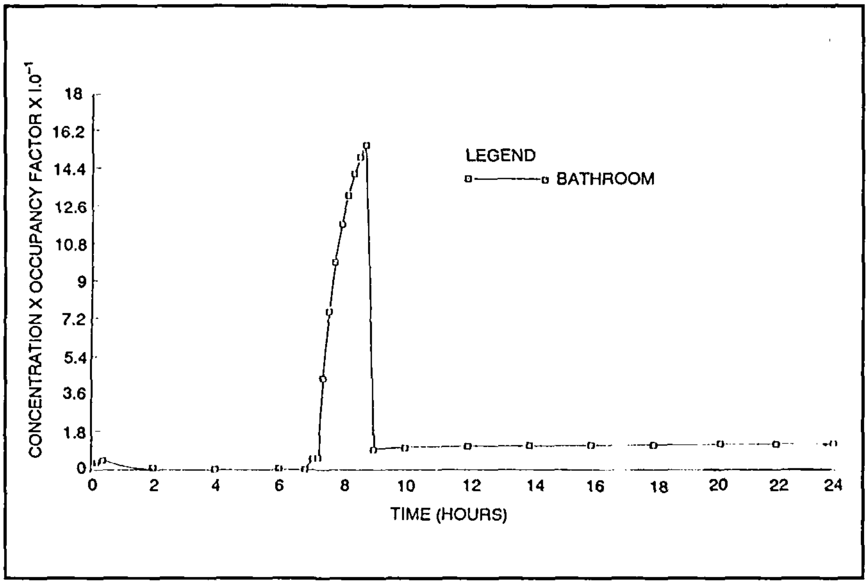

Figure 8.

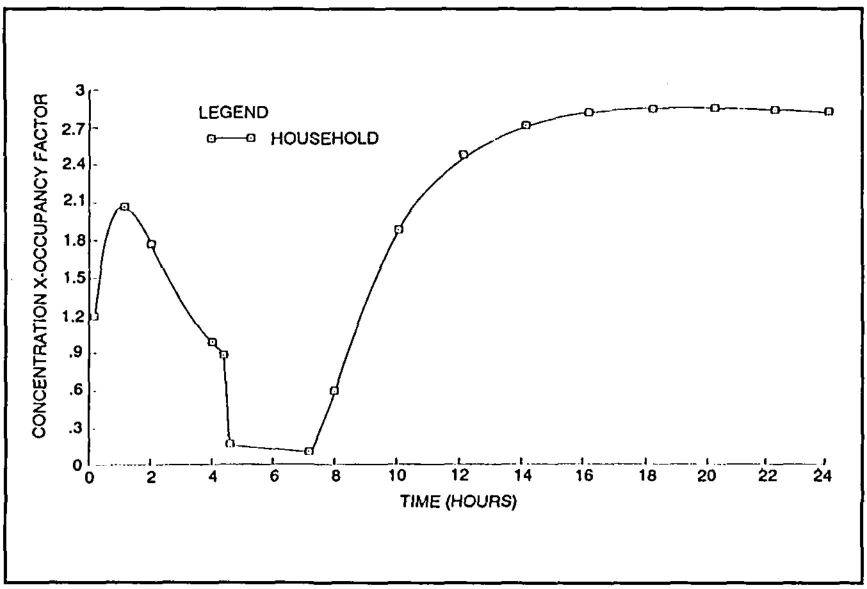

Figure 9.

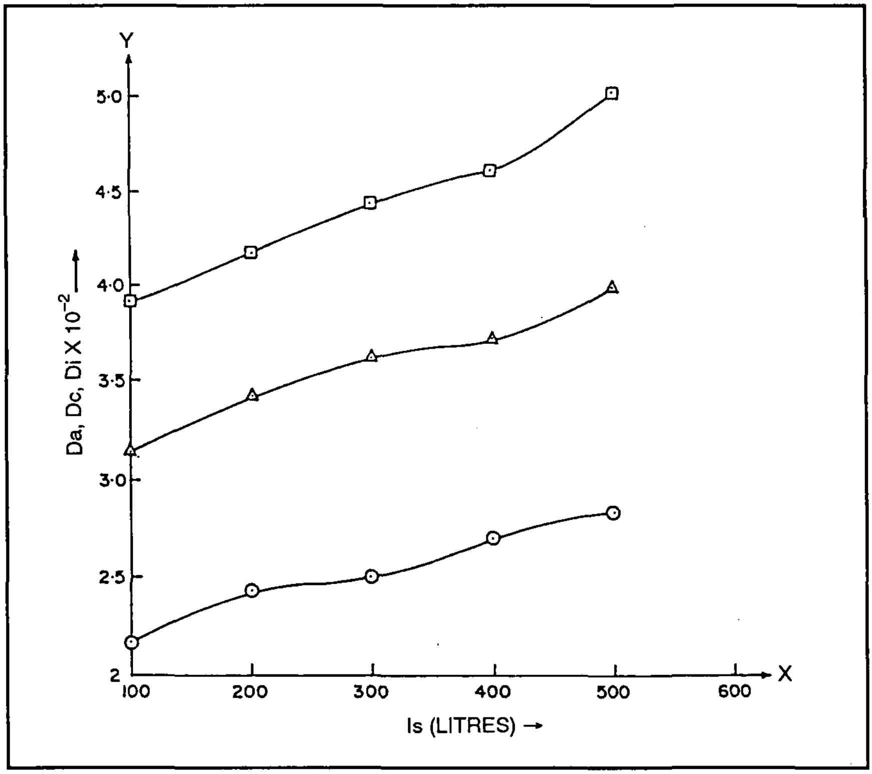

Figure 10. Amount of water used in shower versus dose rate.

and bathroom change, the maximum dose observed is in the case of infants. On the other hand, exposure dose levels for adults are maximum, in case the volume of remaining household is increased. This variation can be attributed to different durations of time spent by different age groups in the three compartments.

DISCUSSION

It is pertinent to note that modeling studies should be able to focus on the extremes of a population that is exposed to a specific contaminant. Integration of environmental and exposure models with toxicokinetic and pharmacodynamic models helps characterize pollutants and areas of concern for acute and chronic effects. This will also decrease uncertainty in the estimates of exposure. The following specific issues need to be investigated as an extension of the modeling exercise:

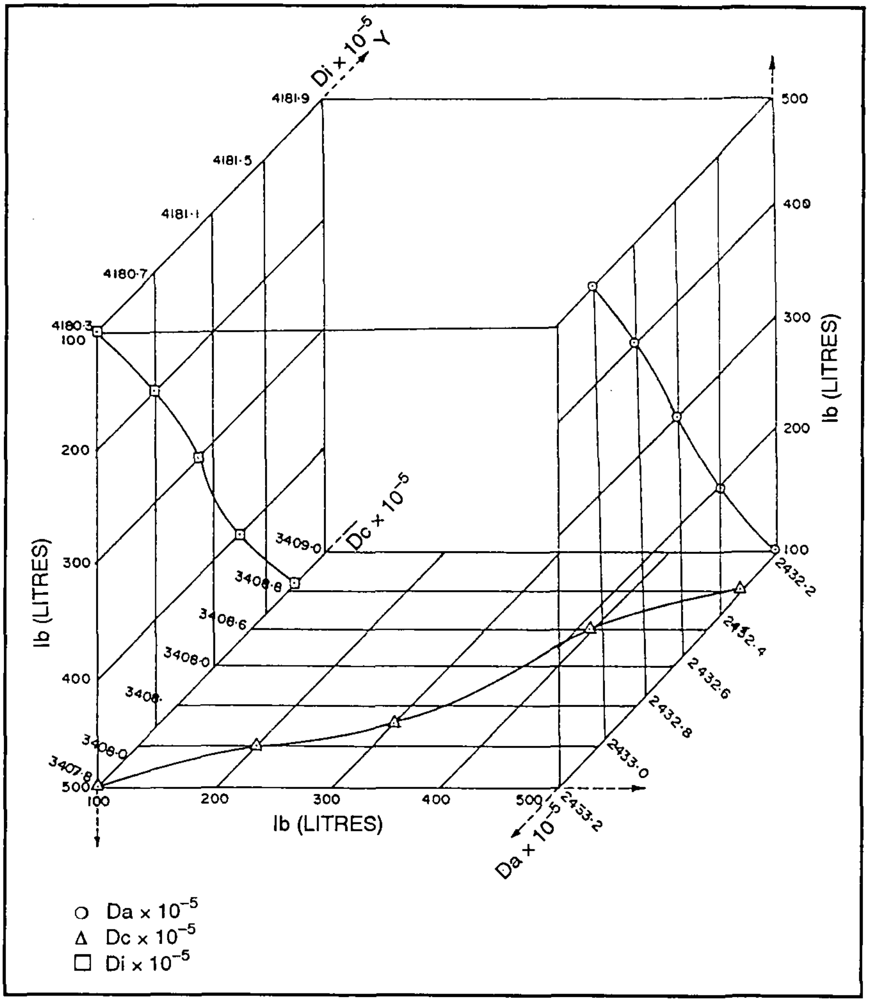

Figure 11. Amount of water used in bathroom versus dose rate.

- Sensitivity analysis of the model to identify and quantify changes on the projected pathway dose factor.
- Incorporation of non-linear inter-compartmental transfers to make the model more precise.
- More extensive characterization of the distribution of exposures within given population groups. This would require the collection of more detailed information on characterization of housing stock, types and numbers of showers

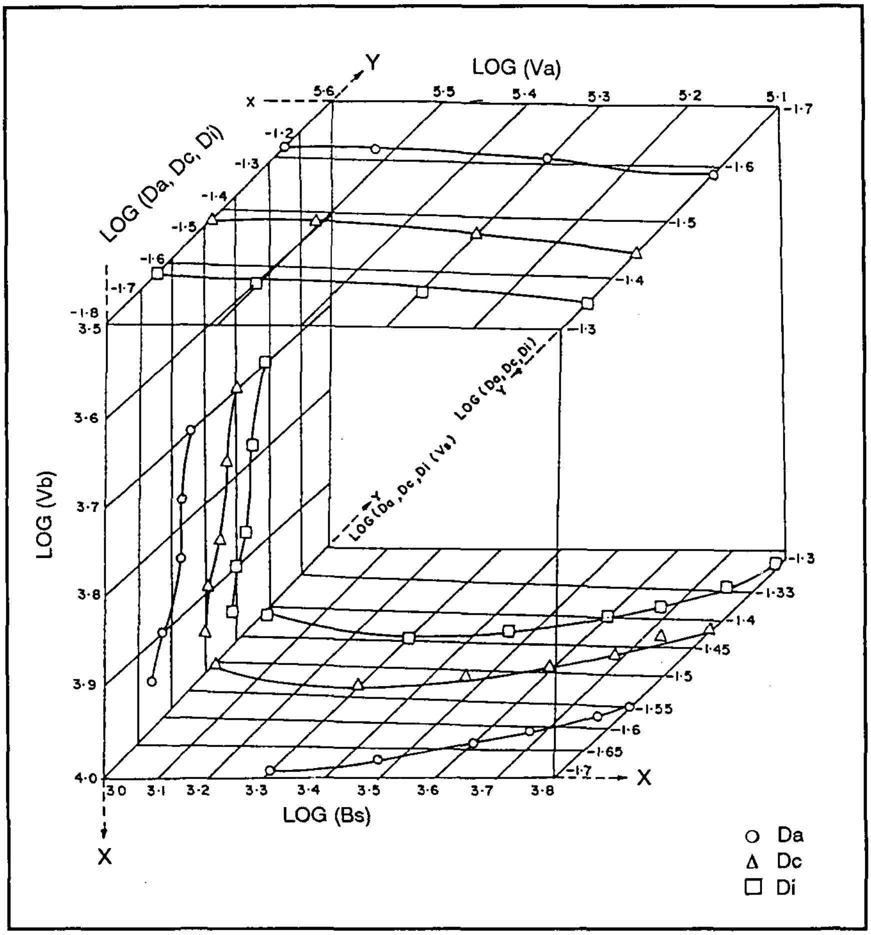

Figure 12. Volume versus dose rate.

and bathroom facilities in each home, water flow rates, water use patterns and occupancy factors.

- More detailed analysis of the parameters with respect to which dose factors are most sensitive.

REFERENCES

1. A. Hamilton, *A Life in Letters*, B. Sicherman (ed.), Harvard University Press, Cambridge, Massachusetts, 1984.

2. L. A. Wallace, Total Exposure Assessment Methodology (TEAM) Study, *Summary and Analysis*, Vol. 1, United States Environmental Protection Agency, Washington, D.C., 1981.
3. J. D. Spengler and M. L. Soczek, *Environmental Science Technology, 18*, pp. 268A-280A, 1984.
4. *Federal Register, 51*, pp. 33992-34054, 1986.
5. *Federal Register, 53*, pp. 48830-48853, 1988.
6. T. E. McKone, *Environmental Science Technology, 21*:12, pp. 1194-1201, 1987.
7. T. T. Shen, T. P. Nelson, and C. E. Schmidt, Assessment and Control of VOC Emissions from Waste Disposal Facilities, *Critical Reviews in Environmental Control, 20*, pp. 43-76, 1990.
8. A. T. Schehata, *Toxicology and Industrial Health, 4*, pp. 277-298, 1985.
9. J. B. Andelman, EHP, *Environmental Health Perspectives, 62*, pp. 313-318, 1985.
10. D. Decker, S. R. Di Mardi, and E. J. Calabrese, *Medical Hypotheses, 15*, pp. 119-124, 1984.
11. K. R. Smith, Biomass Combustion on Indoor Air Pollution: The Bright and Dark Sides of Small is Beautiful, *Environmental Management, 10*, pp. 61-74, 1986.
12. W. R. Ott, *Environment International, 7*, pp. 179-196, 1982.
13. W. R. Ott, *Journal of Clinical Toxicology, 21*, pp. 97-128, 1983-84.
14. D. J. Severn, *Environmental Science Technology, 21*, pp. 1159-1163, 1987.
15. N. W. Schmidke, *In Human Exposure Routes to Persistent Toxic Chemicals in the Great Lakes Basin: A Case Study*, Chapter 10, K. Davies (ed.), Lewis, Chelsea, Michigan, 1988.
16. C. C. Travis and H. A. Hattermer-Frey, *Chemosphere, 16*, pp. 2331-2342, 1987.
17. J. K. Hawley, *Risk Analysis, 5*, pp. 289-302, 1985.
18. K. Sexton and P. B. Ryan, *Assessment of Human Exposure to Air Pollution: Methods, Measurements and Models, Air Pollution, The Automobile and Public Health*, National Academy Press, Washington, D.C., 1988.
19. B. D. Clark, *Perspectives on Environmental Impact Assessment*, University of Aberdeen, 1983.
20. J. B. Stevens and D. L. Swackhamer, *Environmental Science Technology, 23*, pp. 1180-1186, 1989.

Direct reprint requests to:

Dr. J. S. Pandey
National Environmental Engineering Research Institute
Nehru Marg
Nagpur—440 020
India