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Publication Date

2003-06-01

Peer reviewed

RUNNING HEADER:

Persistence as an indicator of population-level intake

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TOTAL WORDS: 5506

Overall multi-media persistence as an indicator of potential for population-level intake of
environmental contaminants

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LBL Report Number: LBNL-53245

ABSTRACT

Although it is intuitively apparent that population-level exposure to contaminants dispersed in the environment must be related to the persistence of the contaminant, there has been little effort to formally quantify this link. In this paper we investigate the relationship between overall persistence in a multimedia environment and the population-level exposure as expressed by intake fraction (iF), which is the cumulative fraction of chemical emitted to the environment that is taken up by members of the population. We first confirm that for any given chemical contaminant and emission scenario the definition of iF implies that it is directly proportional to the overall multi-media persistence, P_{OV} . We show that the proportionality constant has dimensions of time and represents the characteristic time for population intake (CTI) of the chemical from the environment. We then apply the CalTOX fate and exposure model to explore how P_{OV} and CTI combine to determine the magnitude of iF . We find that CTI has a narrow range of possible values relative to P_{OV} across multiple chemicals and emissions scenarios. We use data from the Canadian Environmental Protection Act Priority Substance List (PSL1) Assessments to show that exposure assessments based on empirical observation are consistent with interpretations from the model. The characteristic time for intake along different dominant exposure pathways is discussed. Results indicate that P_{OV} derived from screening-level assessments of persistence, bioaccumulation potential, and toxicity (PBT) is a useful indicator of the potential for population-level exposure.

INTRODUCTION

It is an honor to contribute to this special issue of Environmental Toxicology and Chemistry devoted to the scientific career of Don Mackay. Much of Don's research is concerned with developing quantitative descriptions of the pathways followed by chemicals on their journey from release into the environment to their ultimate removal by chemical degradation or irreversible sequestration; and their entry into human and ecological receptors along the way. A key concept in this regard is the overall persistence (P_{OV}) of contaminants in the multi-media environment including atmosphere, hydrosphere and lithosphere, as articulated by Mackay in 1979 [1]. P_{OV} is the residence time of a contaminant in a defined environment. Its value accounts for the different volumes of, and concentrations and removal rate constants in, the various environmental media. Assessment of P_{OV} has been an area of active research in recent years [2-6], in part because of international efforts to regulate persistent organic pollutants (POPs) and regulatory actions designed to identify chemicals that are persistent, bioaccumulative and toxic (PBTs) [7].

Of particular concern to environmental scientists and policy-makers is the potential of chemical contaminants to contact and enter humans or wildlife through various exposure pathways, and subsequently impart adverse effects. There are several examples of multimedia contaminant fate models based on the principles pioneered by Don Mackay that have been extended to calculate multi-pathway exposures to environmental contaminants [8-10]. In his textbook on modeling techniques using the fugacity concept,

Don states that the task addressed by the book is best summarized by a conceptual diagram showing the pathways followed by environmental contaminants through the environment and into contact with humans. In this paper we use the CalTOX multi-media fate and multi-pathway exposure model to explore the relationship between two aspects of environmental contaminants that are central themes in Don Mackay's research: overall persistence and the potential dose to human populations.

The CalTOX model [11-13] was developed at the University of California for use by the California Environmental Protection Agency in health risk assessments of multimedia pollutants that are exchanged among air, soil, surface water, sediments and ground water. It has been widely used for chemical classification and multimedia risk assessments. CalTOX consists of a fugacity-based multi-media contaminant fate model linked to exposure models that provide estimated daily intake for a human population attributable to a pollutant source in air, water, and/or soil layers. The exposure models in CalTOX encompass twenty-three exposure pathways that relate contaminant concentrations in the multimedia model compartments to concentrations in media with which the human population has contact (i.e., personal air, tap water, foods, household dusts, soils, etc.). Average daily pollutant intake is calculated as the product of the exposure concentrations in these media and an intake factor (for inhalation and ingestion) or an uptake factor (for dermal contact) that relates the concentrations to the potential dose within the population.

The CalTOX model quantifies the source-to-exposure relationship for a system comprised of a pollutant defined by its chemical properties and release scenario, the

environment within which it disperses, and the potentially exposed population. The link between source emissions and population exposure can be expressed as an “intake fraction” (iF), the fraction of material released from a source that is eventually inhaled or ingested. The iF is the simplest possible expression of the source-to-intake relationship for environmental contaminants, which is often a complicated function of the attributes of the chemical, the environment, and the population. Evans et al. [14] have recently reviewed the development and use of iF in exposure assessments in a variety of applications, and Bennett et al. [15] have suggested a standard formalism for expressing the concept.

It is intuitively apparent that population-level exposure to contaminants dispersed in the environment is a function of persistence. If all factors except environmental persistence are identical, the cumulative population-level intake of a pollutant that is more persistent in the environment will be higher than intake of one that is less persistent. However, there is currently no quantitative explanation of the relationship between persistence and population-level pollutant intake. The goals of this paper are to explore the nature of the quantitative relationship between P_{OV} and iF in a multi-media contaminant fate and exposure framework. We make use of both a multi-media, multi-pathway exposure model and data from the Canadian Environmental Protection Act Priority Substance List assessments (CEPA PSL1). As we demonstrate below, the definition of iF implies that it is directly proportional to P_{OV} for any defined chemical and release scenario. We note that the proportionality constant of this relationship has dimensions of time and thus represents the characteristic time for population intake (CTI) of the pollutant from the

environment. We discuss the relative influence of P_{OV} and CTI in describing population-level intake fraction, and the significance of P_{OV} as an indicator of potential for human exposure in screening-level environmental assessments for chemicals.

THEORY AND METHODS

We derive the general relationship between P_{OV} and iF first for a simple case of a single exposure media and single exposure pathway in order to make clear the concept and our approach. We then consider the more complicated case of multiple exposure media and multiple exposure pathways.

Single exposure media and exposure pathway: Inhalation of airborne chemicals

Evans et al. [14] derived equations that define iF for a conservative, volatile contaminant continuously emitted to a well-mixed air shed over an urban region, with base area A (m^2) and mixing height H (m). In their approach, air pollutants are removed from the system only by advection, with wind blowing at a constant velocity u (m/d) perpendicular to one of the sides of the box. Intake by the population of N individuals in the region is by inhalation, with average breathing rate B (m^3/d). For this simple model,

$$iF = (B * N) / (u * H * A^{1/2}) \quad \dots 1$$

Equation 1 expresses intake fraction as the cumulative breathing rate of the population within the region (the numerator) divided by the ventilation rate of an air mass moving through the region (the denominator). The rate of chemical emissions does not appear in the equation because iF is not a measure of absolute exposure of the population. It represents the fraction of chemical put into the system that enters the lungs of a member of the population.

The form of Equation 1 indicates that intake fraction can be viewed as being determined by the rates of two competing processes; uptake of pollutants by the population and irreversible removal from the environmental system. Put another way, iF describes how fast the population is inhaling air relative to how fast air is being brought into and flushed out of the region by the wind. This is readily apparent if the numerator and denominator are divided by the volume of the airshed over the region ($A * H$), thus converting the iF expression into the ratio of two rate constants with units of d^{-1} .

$$iF = k_b / k_{adv} \quad \dots 2$$

Where the numerator is the rate constant for population intake of air by breathing,

$$k_b = (B * N) / (A * H) \quad \dots 3$$

and the denominator is the rate constant for advective removal of chemical from the airshed.

$$k_{adv} = (u * H * A^{1/2}) / (A * H) = (u / A^{1/2}) \quad \dots 4$$

Multiple exposure media and multiple exposure pathways

For a multi-media environmental model consisting of i connected compartments representing various environmental media, the overall rate of clearance of contaminants from the system is a function of chemical partitioning and rates of degradation and advection in each compartment. An overall rate constant for clearance of a chemical from the system (k_{ov}) can be defined [6] as:

$$k_{ov} = \frac{\sum N_i k_i}{\sum N_i} \quad \dots 5$$

where N_i is the mass of contaminant in compartment i and k_i is the rate constant for removal from that bulk compartment, possibly the sum of rate constants representing advection and degradation processes in the compartment. The reciprocal of k_{ov} is the overall persistence:

$$P_{OV} = 1/k_{OV} \quad \dots 6$$

Under steady state conditions, P_{OV} can be calculated as the ratio of the total inventory of contaminant in the environmental system, $\sum N_i$ (g), and the emission rate, E (g/day) [16],

$$P_{OV} = \sum N_i / E \quad \dots 7$$

and, by definition,

$$iF = I/E \quad \dots 8$$

where I (g/day) is the cumulative, steady-state, multi-pathway pollutant intake rate by the population. Multiplying both the numerator and denominator of the right hand side of Equation 8 by $\sum N_i$ and rearranging yields,

$$iF = \frac{\sum N_i/E}{\sum N_i/I} = \frac{P_{OV}}{CTI} \quad \dots 9$$

Where $CTI = \sum N_i/I$, and is defined as the “characteristic time for intake” of the contaminant by the population. CTI is a function of the properties of the chemical of interest and of the environment and the population. As we show below CTI can be characterized according to the dominant exposure pathway for the contaminant of interest. In our earlier example of iF based on inhalation for a contaminant confined to the air of a region (Equations 1 and 2), we noted that iF was the ratio of the population breathing rate to air-shed ventilation rate. With the introduction of CTI we can reinterpret iF in the single media example as the ratio of the P_{OV} for the air shed, which is

the measure of the effective lifetime of a molecule in the air mass of the airshed, and CTI, which is a measure of the average time for a molecule to enter a human lung. We extend this to the multi-media multi-pathway system with P_{OV} representing the effective lifetime of a molecule in the multi-media region and CTI representing the how long on average it takes a molecule to enter a human by any pathway and route.

Equation 9 is an informative way of expressing iF because it makes clear that for a given chemical in a defined system of environment and population, iF is directly proportional to P_{OV} . The longer a chemical resides in the environment the more likely it is to be taken up by a member of the population.

MODEL-BASED COMPARATIVE EXPOSURE ASSESSMENTS

In this section we explore the relationships between iF , P_{OV} , and CTI in a model system using the CalTOX model. An interpretation of empirical exposure assessment data using these concepts is presented below.

Approach

The CalTOX model [11] contains databases of (1) physico-chemical properties, partition coefficients and media-specific degradation rates for 309 organic chemicals that are contemporary environmental contaminants, (2) landscape parameters for various states and regions in the United States, and (3) exposure factors for various population cohorts based on gender and age. In order to explore the relationship between iF and P_{OV} we ran

the CalTOX model for all 309 chemicals in the CalTOX database using the archetypal “US” landscape parameters [12], representing the 48 conterminous United States with an assumed population of 280,000,000 persons, and the “LCIA” exposure factors, which are appropriate for assessing contaminant intake in the general population of an industrialized country [12]. The exposure pathway for population-level intake due to ingestion of breast milk by infants was neglected in this analysis of life-time equivalent population exposure.

We ran CalTOX for each of the 309 organic chemicals emitted individually to air, water and surface soil (927 total model runs). Model results gathered for each run included iF and P_{OV} (calculated according to Equations 8 and 7 respectively) and CTI (calculated as $\sum N_i / I$ and verified as numerically equal to iF/P_{OV}), and exposure pathways data describing calculated cumulative population exposure by relative contributions from inhalation, ingestion and dermal routes.

Results


We first consider results for emissions to air. Figure 1 shows the steady-state relationship between iF and P_{OV} from CalTOX for the set of 309 chemicals released continuously to the atmosphere. Our regression analysis of these results indicates that 85% of the variability among chemicals in the logarithm of iF can be explained by the linear relationship with the logarithm of P_{OV} . The slope of the plot of $\text{Log}(iF)$ versus $\text{Log}(P_{OV})$ is not significantly different from unity at the 95% confidence level. If the slope is

assumed to be 1, the empirical relationship between iF and P_{OV} for this set of chemicals can be expressed as:

$$\text{Log}(iF) = \text{Log}(P_{OV}) - 6 (\pm 0.82) \quad \dots 10$$

or, equivalently,

$$iF = \frac{P_{OV}}{10^6} (\times/\div 6.6) \quad \dots 11$$

Equation 11 implies that the median estimate of CTI for the 309 chemicals under this  defined scenario is 10^6 days. Ninety-five percent of the actual CTI values calculated for the data set fall within a factor of 6.6 of this value. Three lines of constant CTI are plotted in Figure 1 for reference.

Inspection of Figure 1 reveals that P_{OV} for the 309 chemicals emitted to air spans five orders of magnitude and that the chemicals are fairly evenly distributed across this range. In contrast, CTI spans less than three orders of magnitude, and 301 of the 309 chemicals (97.4 %) lie within an order of magnitude of the central estimate derived from regression analysis, 10^6 days, regardless of whether the dominant exposure pathway for the population is inhalation or ingestion of food and water.

In order to further explore this relationship, we consider the two outlying chemicals that give rise to the shortest and longest CTI among the 309 chemicals. These chemicals are, respectively, di-n-octyl phthalate (point A in Figure 1) and *m*-dinitrobenzene (point B in Figure 1). Di-n-octyl phthalate is extremely hydrophobic and has low volatility (Log

Kow = 9.5, Log Koa = 13.8). In the atmosphere it partitions almost entirely to aerosols and is deposited to vegetation, soil and surface water by wet and dry deposition. In the CalTOX assessment its dominant pathway for human exposure is deposition to vegetation with transfer to agricultural products including meat, milk and eggs, and subsequent ingestion. The short CTI for di-n-octyl phthalate is therefore attributable to its high potential for bioaccumulation in the terrestrial food chain. At the opposite extreme is *m*-dinitrobenzene, which is somewhat soluble in water and semi-volatile (Log Kow = 1.5, Log Koa = 6.5). Its dominant exposure pathways for emissions to air are inhalation (35%) and transfer to exposed produce followed by ingestion by the population (58%). However, 95% of the steady-state inventory of *m*-dinitrobenzene is sequestered in soil and pathways for transfer from soils to exposure media are inefficient. The inventory of contaminant in soil therefore controls P_{OV}, but does not contribute appreciably to population intake.

Figure 2 shows iF as a function of P_{OV} for emissions to surface water. As was the case for emissions to air, a regression analysis yields a slope near unity. Three hundred of the 309 chemicals (97.0 %) have CTI within an order of magnitude of 10⁶ days, while P_{OV} spans 7 orders of magnitude. The chemical with the shortest CTI for emissions to water is Aldrin (point C in Figure 2). Aldrin is highly hydrophobic (Log Kow = 6.9) and has the highest aquatic bioconcentration factor (BCF) among chemicals in the CalTOX database. The dominant pathway for population exposure to Aldrin emitted to surface water is by ingestion of fish, which accounts for 99.8% of total intake. Benzo[a]pyrene (B[a]P) has the longest CTI in this scenario (point D in Figure 2). Although B[a]P has

similar hydrophobicity to Aldrin ($\text{Log } K_{ow} = 6.3$), its BCF is low because it is assumed to be metabolized by fish. The dominant exposure pathway for B[a]P emitted to water is therefore by ingestion of tap water, which accounts for its long CTI relative to other chemicals in the database.

Figure 3 shows iF as a function of P_{OV} for emissions to the surface soil compartment. In this case, we do not see an obvious linear relationship between $\text{Log}(iF)$ and $\text{Log}(P_{OV})$ for the group of 309 chemicals. The absence of the linear relationship is especially notable among chemicals for which ingestion is the dominant pathway for exposure. We believe this comes about because many of these chemicals are not efficiently mobilized from soil into the atmosphere, surface water or vegetation where they can be consumed in drinking water or food products. Stated another way, the CTI of contaminants that are sequestered in soils is long relative to the same chemicals in air or surface water. Chemicals that efficiently volatilize from soils and have inhalation as the dominant exposure pathway have CTI that is comparable to the other emission scenarios because the rate limiting process for their uptake is the breathing rate of the population.

In order to determine whether degradation in a specific compartment was controlling the calculated iF , we compared iF against the media-specific half-lives used as inputs to the CalTOX model for the 309 chemicals. This comparison is illustrated in Figure 4 using results for emissions to air only. These plots clearly show little or no relationship between iF and the degradation rates in specific media. Regression of $\text{Log}(iF)$ versus

degradation half-lives in air, water, surface soil and sediment yielded R^2 less than 0.02 in all cases.

A relationship is evident between iF and degradation half-life in air, with two distinct regions where the residence time of the contaminants in the atmosphere is dominated by degradation and advective removal. However, for contaminants emitted to air with ingestion as the dominant exposure pathway, air half-life is essentially uncorrelated with iF for the population. The results shown in Figure 4 for emission to air are consistent with other emission scenarios. Within limited ranges of environmental behavior and exposure pathway we have found some apparent dependence of iF on media-specific degradation, but in general degradation half-lives in individual media are not robust indicators of potential for population exposure.

EVALUATION OF EMPIRICAL EXPOSURE ASSESSMENT DATA

Because the forgoing analysis is based primarily on model results, it raises the question of whether the observed relationship of iF to P_{OV} can be confirmed from one or more sets of empirical observations. Few comprehensive assessments of emissions and human exposure have been reported that allow empirical calculation of iF. As a result direct confirmation of the model-based iF to P_{OV} relationship is difficult to construct from monitoring data or experiments. However, we are able to carry out a confirmation of the proposed relationship from an independent evaluation of emissions and exposure that was carried out under the Canadian Environmental Protection Act (CEPA). As an initial

evaluation of the model-based premise, we examined the extent to which the CEPA assessment confirms or refutes the relationship between iF and P_{OV}.

CEPA PSL1 Assessments

Under the Canadian Environmental Protection Act detailed assessments of emissions, environmental fate and human exposure have been carried out for a set of “Priority Substances” [17]. The goal of these assessments is to determine whether the identified substances enter the Canadian environment in quantities sufficient to constitute a danger to human life or health. Environment Canada and Health Canada have collected and reviewed data relevant to rates of emission and human exposure to the CEPA priority substances list (PSL) substances to support these assessments. A review of the CEPA PSL reports provided sufficient information to estimate iF for the Canadian population for the 14 chemicals listed in Table 1, using the following equation:

$$iF = \frac{I}{E} \times \frac{70 \times 30000000 \times 365}{10^9} \quad \dots 12$$

Where I (ug/kg/day) is the estimated daily intake of chemical by adult Canadians and E (kg/y) is the estimated release rate to the Canadian environment. Both I and E were reported for the 14 chemicals in the CEPA PSL1 reports. The constant in this expression converts iF to a dimensionless value by assuming a population of 30 million people in Canada and an average bodyweight of 70 kg. To ensure the intake rate used in the calculation was representative of intake due to environmental contamination, estimates of

intake by inhalation of indoor air or during specific activities such as smoking or refueling a car were not included in the calculation of iF .

Overall persistence was calculated for the 14 chemicals in Table 1 using the equilibrium partitioning approach and generic environmental parameters described by Gouin et al. [18]. Partition coefficients and estimated degradation rate constants in air, water and soil required for the P_{OV} calculations were taken from the CalTOX database [11].

Results

Figure 5 shows iF plotted against P_{OV} for the 14 chemicals from CEPA PSL1. Error bars represent the upper and lower boundaries of iF in cases where ranges of emissions and/or intakes were reported in the CEPA reports. These results, based on real-world estimates of emissions and contaminant intake, are consistent with the model results presented earlier. Linear regression of the CEPA derived relationship between iF and P_{OV} yields a slope that is not statistically different from 1 and a best estimate of CTI of approximately 10^6 days. Although this analysis is not a strict validation of the relationship between iF and P_{OV} , it represents an independent evaluation from empirical data, and based on different assumptions, and provides reasonable confirmation of the approximate relative magnitude of variability in CTI and P_{OV} between environmental contaminants.

DISCUSSION

We present an interpretation of iF as the ratio of rate constants describing two competing processes: removal of contaminant from the environmental system (characterized by P_{OV}) and uptake by the population (characterized by CTI). The present definition is consistent with other conceptualizations of iF as the ratio of cumulative intake rate to emission rate in exposure assessments [15] and as proportional to the ratio of residence time divided by dilution volume for inhalation of contaminated air [14]. Analysis of model results and empirical exposure assessment data indicate that the relationship between $\text{Log } iF$ and $\text{Log } P_{OV}$ in comparative assessments of groups of chemicals is linear. This implies that inter-chemical variability in P_{OV} is larger than inter-chemical variability in CTI , and therefore P_{OV} can be treated as a surrogate measure of potential for population intake in screening-level comparative assessments of chemicals.

The present definition explicitly separates iF into an environmental fate component (P_{OV}) and a population-level exposure component (CTI). P_{OV} is a function of chemical partitioning properties, degradability and properties of the environmental system. CTI is a function of chemical properties, population characteristics and behavior patterns, and the efficiency of transfer of contaminants from the environmental system into media with which the population has direct contact. Viewed in these terms, it is apparent that chemicals can have a relatively high potential for population exposure for two reasons: 1) because they are highly persistent, or 2) because they are efficiently transferred into a pathway for population exposure and intake. The present definition of iF is generally applicable, as we have demonstrated using datasets derived from a fate and exposure model and a real-world population level exposure assessment. These techniques are

particularly meaningful when interpreting the results of multi-media fate and multi-pathway exposure assessments in which there is simultaneous transfer and accumulation of contaminant in air, water, soils and sediments, and exposure by a combination of inhalation, ingestion and dermal contact.

In the model-based analysis of a representative group of chemicals emitted to air or surface water, P_{OV} varies over 7 orders of magnitude while CTI, with only a few exceptions, is restricted to a 2 order of magnitude range. Differences in CTI are evident for different exposure pathways and for different emission scenarios, but these differences are not as dramatic as the range in P_{OV} possible due to inter-chemical differences in degradability and partitioning. These results indicate that, to a first approximation, P_{OV} can be viewed as a surrogate measure of potential for population exposure in comparative screening assessments of chemicals. Because iF is the ratio of P_{OV} and CTI, the range of variability in the data imply that one can predict iF from P_{OV} with an expected uncertainty of approximately two orders of magnitude. But from the case studies above, we show in practice that the residual error in the P_{OV} to iF relationship is one order of magnitude or less. In contrast, relationships between population-level iF and media specific degradation half-lives are not robust, and therefore assessment of P_{OV} in screening-level PBT assessments provides additional information about potential for population exposure that is not available by screening against defined half-life criteria only.

For emissions to soil the direct relationship between P_{OV} and iF breaks down, especially for chemicals that remain entrained in soil. Under this scenario, CTI plays a more important role in determining population iF than in the case of emissions to air or water. To some extent this result is a consequence of the environmental boundaries defined in the assessment. The model environment used in the assessment includes soils at depths where contaminants are considered to be in active circulation in the environment, but are unlikely to contact a member of the population, as evidenced by long CTI.

Typical characteristic times for intake calculated for the US and Canadian populations in these sample assessments are 10^6 days, or approximately 2700 years. The magnitude of the median CTI determined in comparative assessments will be sensitive to landscape properties, population density, and exposure factors used in the assessment. The extremely long CTI reported here should not be misinterpreted as indicating that cumulative contaminant intake will be spread out over several generations. The CTI is a measure of the effective rate constant with which the population is exposed to chemicals under the defined environmental and population scenario. The correct interpretation of the long CTI is that it would take several hundred years for the population to clear the contaminant burden from the environment by taking it into their bodies through exposure pathways.

We have focused in this paper on assessing iF for human populations on a national scale. The relationship between P_{OV} and iF that is suggested in this study should be further explored and evaluated using other data sets and models. Similar analysis for other

species, such as predatory birds or sport fish, is possible, and could provide interesting insights into the relative contribution of contaminant fate and efficiency of exposure pathways in determining the intake of contaminants by different species of wildlife. Similar concepts to those presented here have even been applied to the “intake” of contaminants by entire ecological systems, as demonstrated by calculations of the efficiency of transfer of contaminants to the Laurentian Great Lakes from different regions of North America [19].

ACKNOWLEDGMENT

This work was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) and by the US Environmental Protection Agency National Exposure Research Laboratory through Interagency Agreement # DW-988-38190-01-0, carried out at Lawrence Berkeley National Laboratory through the US Department of Energy under Contract Grant No. DE-AC03-76SF00098.

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Table 1. CEPA PSL1 substances with sufficient data in the assessment to calculate iF for the Canadian population

Chemical	Log Kow	Log Koa	Log Kaw	Degradation Half Lives (h)			
				Air	Water	Octanol	P _{OV} (h)
Benzene	2.18	2.81	-0.63	142	267.6	4565	142
Chlorobenzene	2.81	3.76	-0.95	396	2620	1790	404
1,2-Dichlorobenzene	3.45	4.54	-1.09	840	2500	5320	890
1,4-Dichlorobenzene	3.49	4.46	-0.97	924	2800	12500	973
Tetrachlorobenzenes	4.50	5.92	-1.42	4580	1700	1700	2330
Pentachlorobenzene	5.00	6.55	-1.55	6530	6210	6210	6260
Hexachlorobenzene	5.54	6.91	-1.37	20300	36800	11200	11600
3,3'-Dichlorobenzidine	3.58	9.57	-5.99	0.05	0.05	2500	0.200
1,2-Dichloroethane	1.45	2.76	-1.31	1080	19600	2610	1120
Dichloromethane	0.90	1.38	-0.48	8090	420	420	7290
Trichloroethylene	2.50	2.96	-0.46	83	2920	22300	83.6
Methyl methacrylate	1.38	3.24	-1.86	1.98	269	420	2.27
Toluene	2.68	3.26	-0.58	57	312	682	57.5
Xylenes	3.11	3.67	-0.56	23.3	420	363	23.6

FIGURE LEGENDS

Figure 1. Relationship between population intake fraction (iF) and overall persistence (P_{OV}) for 309 organic chemicals emitted to air. Lines of constant characteristic time for intake (CTI) are indicated. Data points A (di-n-octyl phthalate) and B (*m*-dinitrobenzene) are discussed in the text.

Figure 2. Relationship between population intake fraction (iF) and overall persistence (P_{OV}) for 309 organic chemicals emitted to surface water. Data points C (aldrin) and D (benzo[a]pyrene) are discussed in the text.

Figure 3. Relationship between population intake fraction (iF) and overall persistence (P_{OV}) for 309 organic chemicals emitted to surface soil.

Figure 4. Relationships between population intake fraction (iF) and degradation half-lives in individual media (air, water, soil and sediment) for 309 chemicals emitted to air.

Figure 5. Relationship between population intake fraction (iF) and overall persistence (P_{OV}) for 14 chemicals from the Canadian Environmental Protection Act Priority Substance List (PSL1) Assessments.

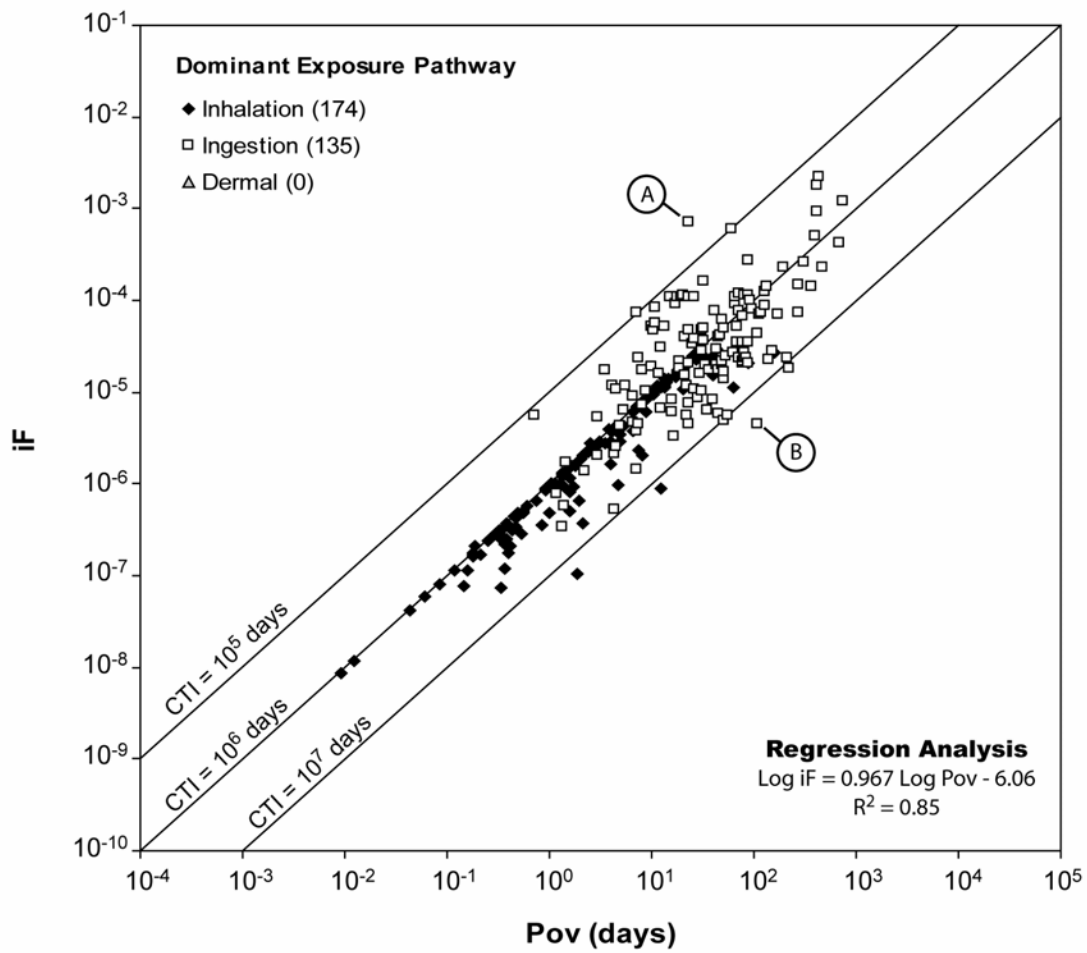


Figure 1.

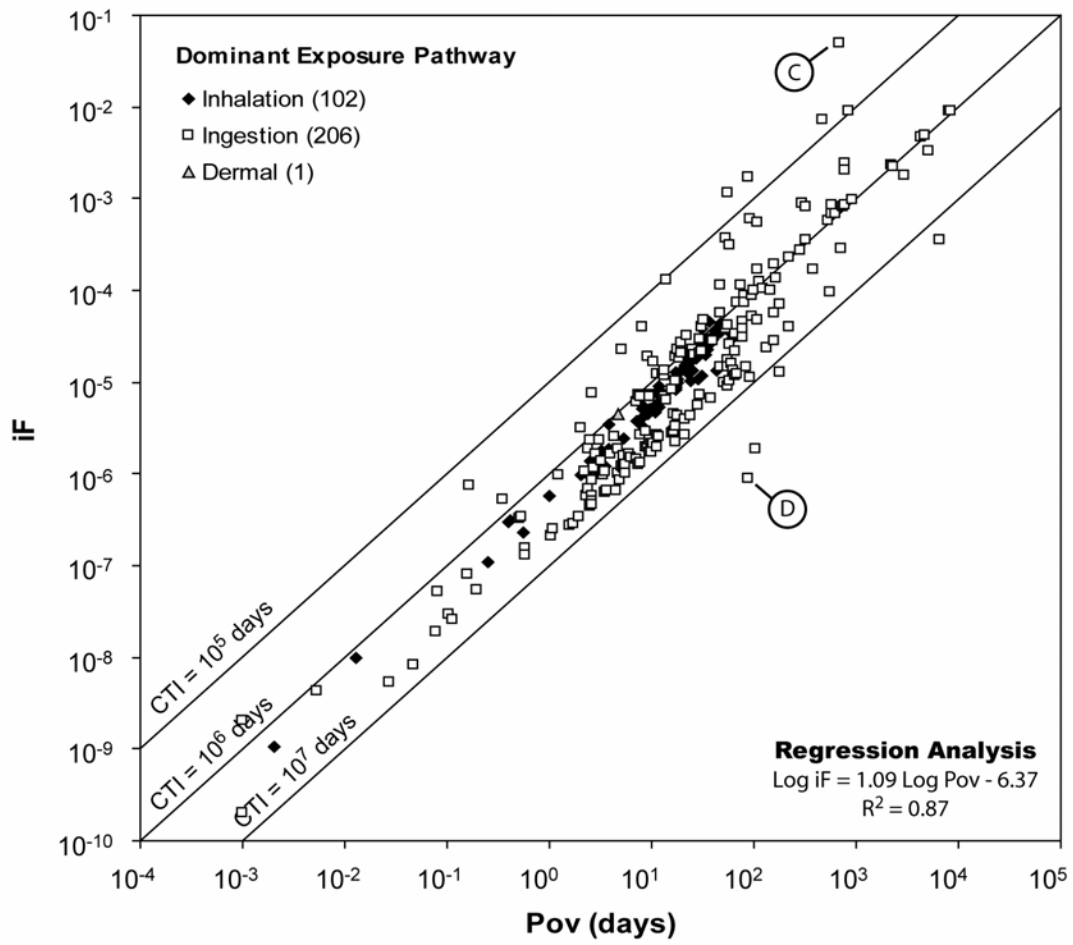


Figure 2.

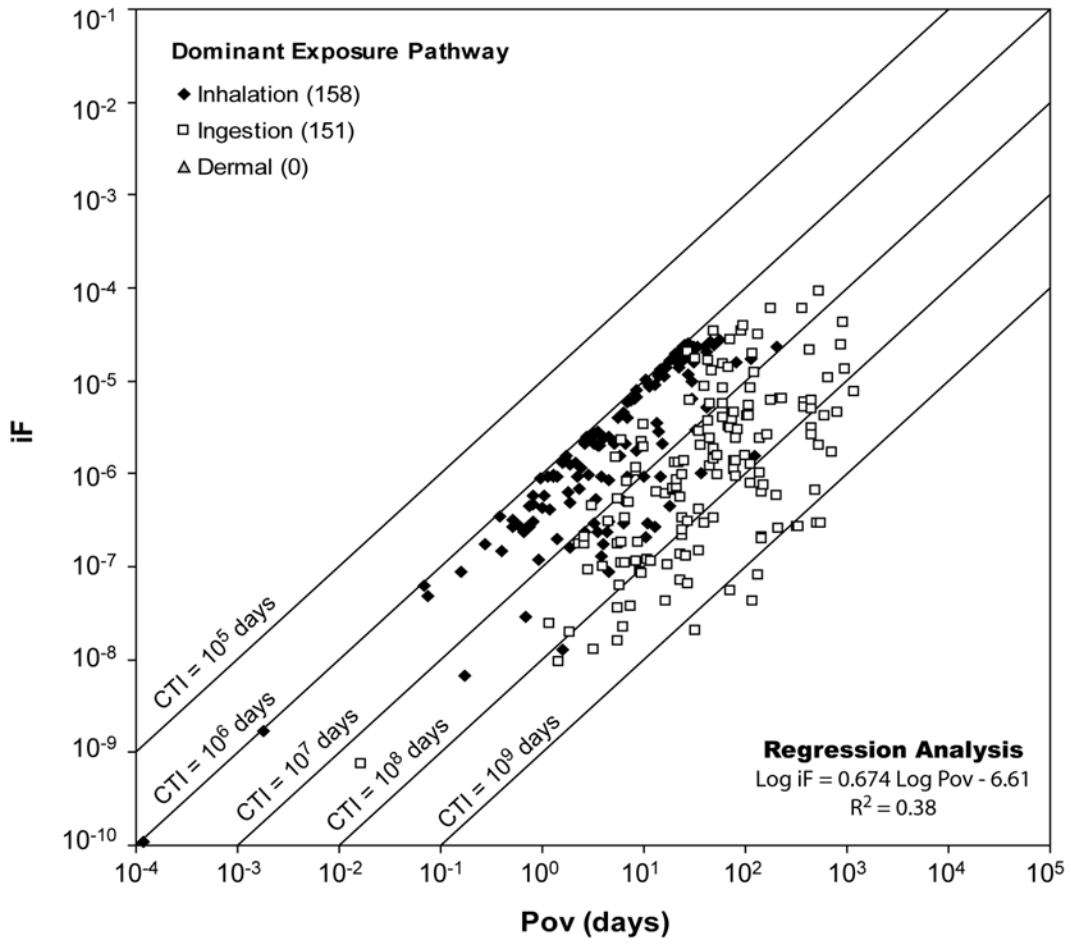


Figure 3.

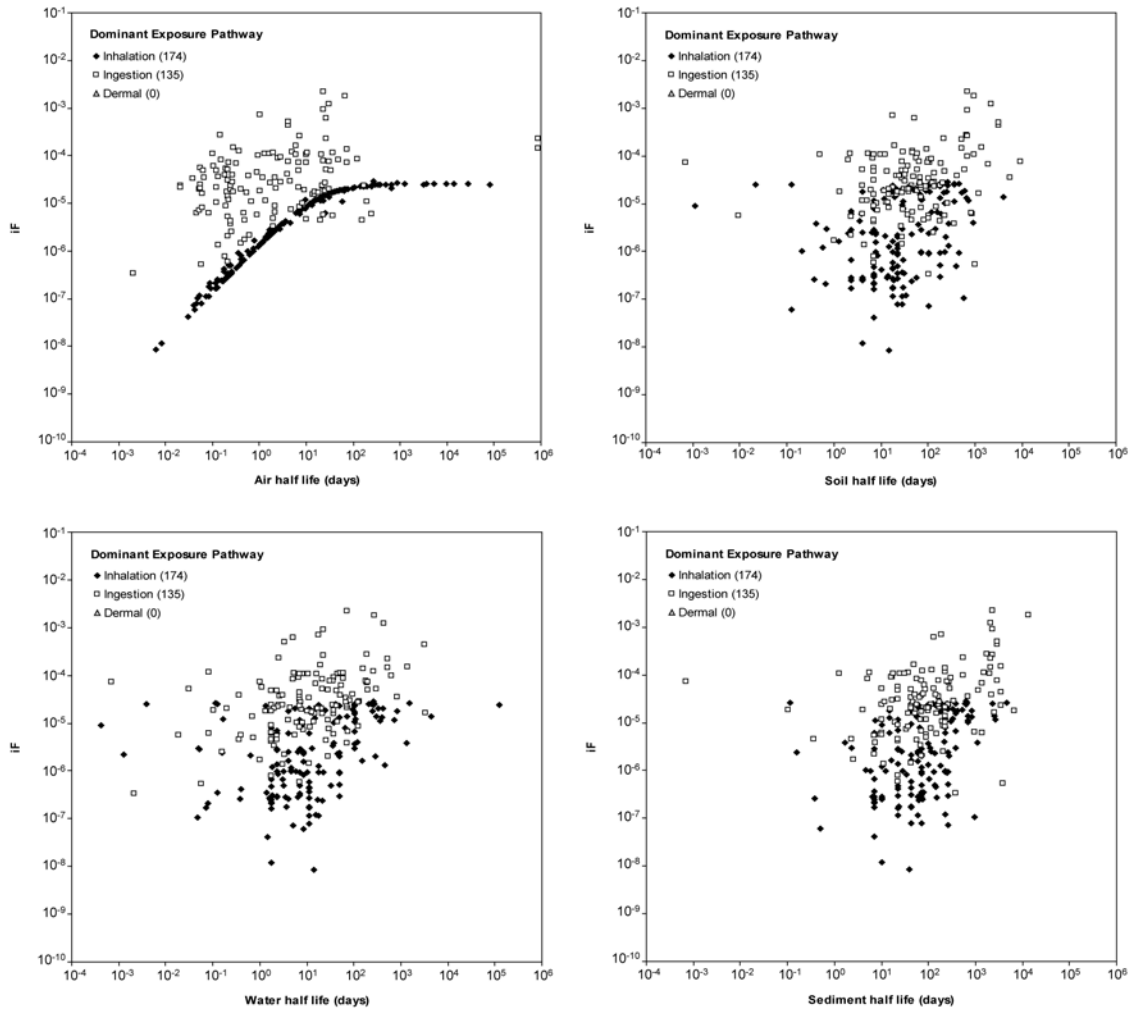


Figure 4.

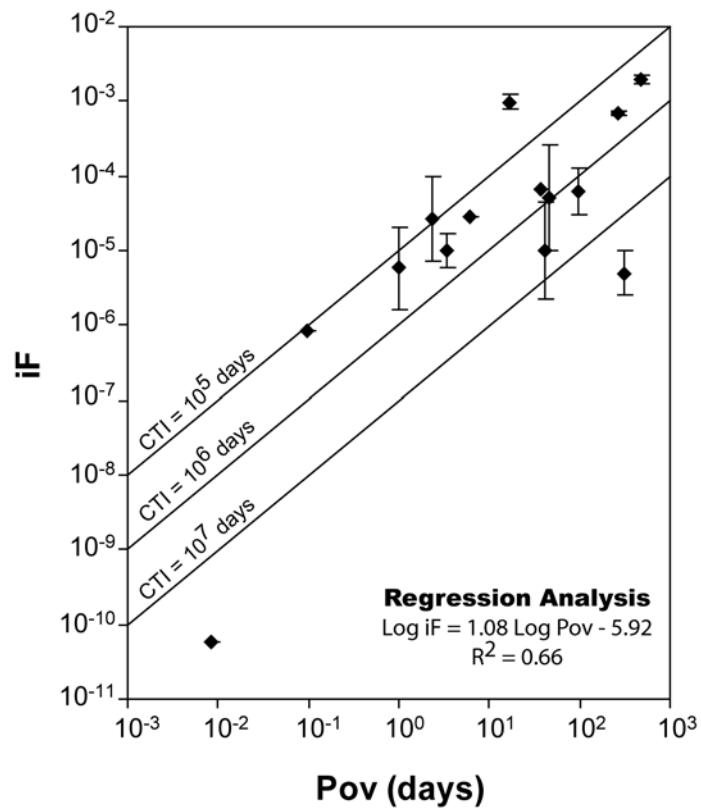


Figure 5.