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Short communication

Parameter sets for upper and lower bounds on soil-to-indoor-air contaminant attenuation predicted by the Johnson and Ettinger vapor intrusion model

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Abstract

Migration of volatile chemicals from the subsurface into overlying buildings is known as vapor intrusion (VI). Under certain circumstances, people living in homes above contaminated soil or ground water may be exposed to harmful levels of these vapors. A popular VI screening-level algorithm widely used in the United States, Canada and the UK to assess this potential risk is the "Johnson and Ettinger" (J&E) model. Concern exists over using the J&E model for deciding whether or not further action is necessary at sites, as many parameters are not routinely measured (or are un-measurable). Using EPA-recommended ranges of parameter values for nine soil-type/source depth combinations, input parameter sets were identified that correspond to bounding results of the J&E model. The results established the existence of generic upper and lower bound parameter sets for maximum and minimum exposure for all soil types and depths investigated. Using the generic upper and lower bound parameter sets, an analysis can be performed that, given the limitations of the input ranges and the model, bounds the attenuation factor in a VI investigation.

Keywords: Vapor intrusion; Johnson and Ettinger model; Risk assessment

1. Introduction

Under certain circumstances, people living in homes above contaminated soil or ground water may be exposed to harmful levels of organic vapors. Several challenges exist in evaluating the vapor intrusion (VI) pathway. There are potential indoor-air sources for common contaminants such as benzene and toluene including consumer products and building supplies. Additionally, ambient air surrounding a home may itself be contaminated with common VOCs that may or may not be associated with a subsurface source. These alternate sources confound indoor-air measurements and make it difficult to apportion the contribution from subsurface contamination. Often, models are used to determine if a potential indoor inhalation exposure pathway exists and, if such a pathway is

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complete, whether long-term exposure to VOCs increases the occupants' risk for cancer or other toxic effects to an unacceptable level. While several VI models have been developed (Little et al., 1992; Sanders and Stern, 1994; Ferguson et al., 1995; Jeng et al., 1996; Krylov and Ferguson, 1998; Ririe et al., 1998; Olson and Corsi, 2001; Parker, 2003; Abreu and Johnson, 2005), the Johnson and Ettinger (Johnson and Ettinger, 1991) screening-level algorithm is often used to determine the completeness of the subsurface-to-indoor-air pathway. Governmental environmental agencies, including those of Canada, the United States, the United Kingdom, and several US states, use the J&E model to develop screening concentration levels or to assess site-specific conditions (Tillman and Weaver, 2006). Concern exists over using the J&E model for screening sites for potential VI, in part, because uncertainty of model input parameters might play an underappreciated role in screening decisions. In our previous work, we developed an approach to determine the assessment uncertainty associated with synergistic effects of input parameter uncertainty (Tillman and Weaver, 2006). The software developed for that analysis could be used for site-specific uncertainty analysis (http://www.epa.gov/athens/onsite). It is of interest, however, to determine if generic-bounding cases can be developed from the uncertainty analysis. Such a result would permit greater confidence in using single-parameter sets for estimating exposure from the model, as their conservative or non-conservative nature would be known. The purpose of this short communication is to establish the existence of, and then identify, upper and lower bounding parameter sets for the Johnson and Ettinger (J&E) model based on uncertainty analyses incorporating interaction of all model parameters over their USEPA-recommended range of values.

2. Background

The J&E VI model (Johnson and Ettinger, 1991) assumes contaminants are transported through the vadose zone by diffusion, described by Fick's Law, from the contaminant source to a region near the building. Gas-phase contaminants enter a building by diffusion and/or soil–gas advection through foundation cracks. Once contaminants enter a structure they are assumed to be instantaneously and completely mixed by the building's air exchange with non-contaminated outdoor air. The solution to the J&E model is an "attenuation coefficient" *alpha* (α), defined as the ratio of the contaminant concentration in the building to the contaminant concentration at the source (Johnson and Ettinger, 1991). This definition of attenuation leads to some confusion in practice as a *higher* attenuation factor results in *increased* estimated risk. Additional relationships for pressure-driven soil gas entry flow rate, risk level, and hazard index as well as look-up tables for capillary-zone moisture content and capillary-zone thickness were added by the USEPA in their spreadsheet version of the J&E model. Paul Johnson (Johnson, 2005) discusses the differences between the original J&E model and the USEPA spreadsheets and introduces grouped parameters to help further constrain the range of reasonable attenuation factors.

The J&E model was implemented in a Java package called the Model Development Platform (MDP) (Weaver, 2004) to assess its uncertainties and to analyze parameter sets that produce the extremes of high and low risk (see Tillman and Weaver, 2006 for details). In the work presented by Tillman and Weaver (2006), ranges of parameters were used as inputs to drive an uncertainty analysis. The presumption of the work was that previously reported one-at-a-time sensitivity analysis underestimated the actual uncertainties that arise from multiple-parameter uncertainty. The results showed orders-of-magnitude increase in estimated uncertainty over the one-at-a-time analysis. Here, the previous work is used to define the existence of generic-bounding parameter sets. The nine parameters of the J&E model that were treated as uncertain include the subsurface system temperature, source depth, soil gas flow rate into the building, mixing height, floor-wall crack width, air exchange rate, porosity, moisture content, and residual moisture content. The parameter values in Table 1 were drawn from the EPA Office of Solid Waste and Emergency Response (OSWER) VI Draft Guidance (US Environmental Protection Agency, 2002) and use the ranges of values either explicitly indicated or set to an amount of variation equal to $\pm 25\%$ of the OSWER default value. A 10×10 m structure having a basement with a floor 2 m below grade was simulated. Depths to contaminant source of 4.75, 9, and 20 m were chosen to represent shallow, medium, and deep contaminant sources. Soil types of clay, sandy loam, and sand were chosen to investigate the range of coarseness represented in the soil conservation service (SCS) soil types.