Predicting Time-Dependent Vapor Intrusion Risk: The Role of Multicomponent NAPL Sources

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Abstract:

Vapor intrusion (VI) is a major pathway by which volatile organic compounds (VOCs) migrate from contaminated subsurface sources into indoor environments, posing significant risks to human health. Conventional VI models typically rely on steady-state assumptions and single-point risk estimates, often neglecting temporal variability and the multicomponent nature of contaminant mixtures. This study presents a one-dimensional numerical VI model to evaluate the time-dependent evolution of human health risk from multicomponent NAPL sources (e.g., gasoline). The model incorporates multicomponent phase partitioning governed by Raoult's law, simultaneously with vapor diffusion simulated using a finite difference approach. It accounts for coupled mass transfer and chemical interactions across soil, aqueous, NAPL, and vapor phases throughout the subsurface domain, enabling a more realistic representation of vapor generation and migration processes. Results show that partitioning significantly alters indoor air concentrations and both cancer and non-cancer risk profiles over time. Early-time and long-term risk patterns differ markedly, with dominant compounds shifting during different exposure stages. In addition, free-phase NAPL formation acts as a persistent secondary source, influencing long-term exposure conditions. Comparative analysis with conventional screening-level approaches indicates that simplified models may underestimate or overestimate risk, with differences reaching up to an order of magnitude under comparable conditions. Overall, the findings highlight the importance of incorporating time-dependent processes and multicomponent interactions in VI modeling. This approach improves the accuracy of exposure assessment and supports more reliable environmental decision-making and protection of indoor air quality and human health.

Keywords:

Vapor intrusion, time-dependent risk assessment, multicomponent partitioning, NAPL, indoor air quality, human health.