Vapor Intrusion from Subsurface to Indoor Air: Biodegradable Petroleum Vapors versus Recalcitrant Chemicals

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ABSTRACT

Interpretation of vapor transport from the subsurface to indoor air is discussed using a series resistance model, including resistance across the building envelope, the foundation in contact with soil, and a layer of soil separating the foundation from the vapor source. This conceptual model is directly applicable for recalcitrant chemicals, and with minor modification is also applicable for aerobically degradable petroleum hydrocarbon vapors and oxygen. Near worst-case indoor air bounding conditions are discussed. Of note is that, with foundations characterized by effective airflow through the foundation, near worst-case indoor air concentrations for recalcitrant chemicals occur for the highest effective foundation airflow. This would typically be described as a dirt floor or cobblestone foundation. For aerobically biodegrading chemicals, the opposite condition of lowest effective foundation airflow often results in near worst-case indoor air concentrations, specifically when oxygen availability below the foundation is limited. This minimum effective airflow may be diffusion-limited, and would typically occur for a highly intact concrete slab or basement foundation.

SUMMARY

Estimates for near worst-case conditions of vapor transport from the subsurface to indoor air for both non-biodegrading chemicals and aerobically biodegradable petroleum hydrocarbons are examined. For both non-biodegrading chemicals and aerobically biodegradable chemicals, near worst-case indoor air concentrations are expected to occur for minimum foundation to subsurface vapor source separation distances; maximum soil air void space and resulting maximum effective vapor diffusion rates in soil; and minimum building indoor air exchange.

With respect to building foundations, however, opposite worst-case trends are evident for non-biodegrading chemicals and for aerobically biodegradable chemicals. This occurs for aerobically biodegradable chemicals specifically when oxygen presence in the subsurface is limited by the building foundation.

Prior work on characterizing building foundations has been primarily applied in determining average foundation resistance to vapor flow, often quantified as an effective air flow rate through the foundation of approximately 1 to 10 L/min for an average concrete foundation of 100 m^2 in contact with the ground. Analysis has indicated, however, that potential near worst-case indoor air concentrations occur at the extremes of the foundation parameter distribution (maximum and minimum effective foundation air flow rates, for example), not at the central average. And that the worst-case indoor air concentrations for non-biodegrading chemicals and aerobically biodegradable chemicals are likely to occur at the opposite extremes of foundation types.

Non-degrading subsurface chemicals show the highest potential indoor air impact for low vapor resistance building foundations, typically characterized, for example, as a dirt floor or cobblestone foundation. Estimated indoor air concentrations for low vapor resistance foundations and other near worst-case parameters are consistent with measured upper bound indoor air to subsurface concentration ratios for recalcitrant chemicals. The predicted near worst case indoor concentrations can be substantially higher than indicated by average foundation parameter assumptions. In addition, estimated indoor air concentrations show a uniform decrease with increasing foundation resistance to vapor flow. The lowest indoor air concentrations will occur for the highest foundation resistance to vapor flow.

Aerobically degrading chemicals require oxygen in the subsurface to biodegrade. Oxygen reaches the subsurface, and subsurface chemicals reach indoor air by passing through the building foundation. Oxygen and vapor transport through a building foundation is driven both by diffusion and cyclic (in/out) pressure driven advection.

For varied foundation resistance, indoor air concentrations for aerobically biodegrading chemicals do not show a uniform trend, but instead often show a local minimum. This minimum occurs when the effective airflow through the foundation (including oxygen) is equal to that required for maximum aerobic biodegradation of subsurface chemical vapors. From this minimum point, higher estimated indoor air concentrations will occur both when the presence of oxygen in the subsurface is reduced by higher foundation resistance, and when subsurface chemical vapor transport into indoor air increases through a lower foundation resistance. Of the two extremes, limited oxygen conditions below a building foundation appear to be more significant. That is, near worst-case indoor air concentrations under oxygen limited conditions occur at the upper bound of high foundation resistance to vapor flow.

In application, these scenarios for potential worst case conditions require comparison of estimated indoor air concentrations against applicable indoor air criteria. If the near worst-case conditions meet indoor air criteria, other combinations of parameters and scenario characteristics would also meet the applicable indoor air criteria.

The analysis applies a series resistance model, in which relevant parameters are grouped together into resistance terms for the building enclosure (walls and roof); the building foundation (in contact with soil); and the diffusive soil layer between the building and a vapor source. This conceptual model is directly applicable for non-degrading chemicals. With minor modification the conceptual model is also applicable for petroleum hydrocarbon vapors in aerobic degradation with oxygen in soil, and the resistance terms are substantially the same. Near worst case bounds have been determined for the resistance terms, rather than the component variables in each resistance term.

Foundation resistance is identified as a key parameter. Quantified in terms of an effective air flow rate, values range between approximately 0.23 to 60 L/min through a 100 m^2 foundation. Upper values (37 to 60 L/min) are typical for a dirt floor or cobblestone foundation. The lower range value is not zero. Lower range values (0.23 to 28 L/min) are based on measured diffusion rates through intact concrete and measurements for buildings with highly intact concrete foundations. The overall range of values is wider than indicated in similar prior summaries (approximately 1 to 10 L/min), but shows a similar median.

While foundation resistance is empirically quantified using an effective air flow rate, it could also be effectively parameterized using effective diffusion through a foundation. Both are based on chemical concentration measurements across a foundation and are functionally equivalent in estimating time-averaged steady-state chemical transfer across a foundation, when chemical degradation losses within the foundation are negligible.