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Penetration Rates of Pb in the Soil Calculated by a Numerical Model

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Anthropogenic Pb reaching the soil tends to accumulate mainly in the top soil and the extent of Pb mobility in the soil profile is a rather controversial issue. Here we present a numerical model based on Pb concentrations in a roadside soil. Since most soil Pb is associated with the soil particles, Pb movement in the soil profile should be considered in terms of particle transport. Downward transport of small enough particles is expected to be similar to that of solutes and, therefore, can be expressed by the advective-dispersion equation with an additional parameter, the filter coefficient:

$$R\frac{\partial C}{\partial t} = D_p\frac{\partial^2 C}{\partial^2 z} - V_p\frac{\partial C}{\partial z} - V_p\lambda C$$

where R is the retardation factor, the subscription p stands for particulate, D_p and V_p are the particulate coefficients of dispersion and advection, respectively, C is the concentration of the solute species, and λ is the filter coefficient. In order to solve this equation, certain boundary and initial conditions had to be assumed. These include: the initial concentration condition C_0 is the natural level of the soil, t=0 at T=1966, and the concentration at the surface (z=0) depends on Pb input ($C_{(0,t)} = f(t)$). Since petrol-Pb input to the soil surface is variable and could not be approximated by a simple analytical function, a numerical solution was applied. The input function for the simulations was calculated using (1) petrol consumption in Israel, (2) concentration of Pb in petrol, and (3) traffic volume on the Jerusalem - Tel-Aviv highway. The simulation was carried out for a soil profile located 8 m from the highway, which was sampled up to a depth of 13 cm in intervals of one cm. The simulation was applied for whole soil Pb and for various soil components. The simulation produced whole soil Pb velocity of 0.07 cm/yr. Because the carbonate and Fe-oxide components dominate the anthropogenic fraction of Pb in the soil (~80%) they have similar values to the whole soil rate. However, the remainder soil components, organic matter and alumino-silicates produced lower velocities (0.02-0.03 cm/yr), presumably due to higher retardation factors. Based solely on isotopic composition of Pb in the studied roadside soils, Pb velocities of 0.3-1 cm/yr were calculated. These values are an order of magnitude higher than the rates calculated by the numerical model, which is based only on Pb concentrations. Therefore, a faster mode of Pb movement has to be implied to account for the isotopic data. It is possible, therefore, that the penetration of petrol Pb in the soil occurs in two distinct modes which can be viewed only by combining Pb concentration with the isotopic composition. The majority of Pb accumulates in the upper part of the soil and is subjected to slow particle downward movement as depicted by Pb concentrations, whereas a small fraction of the anthropogenic Pb penetrates the entire depth of the soil at a velocity of up to one cm/yr. Rough calculations were made in order to estimate the portion of Pb penetrating in each mode of transportation. Taking into account the necessary concentration of Pb to create the shift from natural isotopic ratios towards anthropogenic ones, it is suggested that about 5% of the anthropogenic Pb has penetrated in the faster mode, probably as soluble Pb, while the remainder ~95% has been associated with particles and moved ten times slower.