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Nanoparticle surface chemistry control of pollution transfer and human toxicity

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Natural nanoparticles have been shown to control the fate of contaminants in soil and aquifers. Heavy metals, radionucleides and positively charged organics (e.g. antibiotics, prion proteins) are sorbed at the surface of clay particles carrying a permanent negative structural charge (e.g. montmorillonite, halloysite) and silica. Variable charge aluminum and Iron oxide and sulfide nanoparticles retain As, Se, Sb anions at pH below their Point of Zero Charge (PZC) by electrostatic interaction, and at higher pH values via inner sphere complexation, but also via surface redox reactions. Neutral particles (organic matter, neutral clays) interact via hydrophobicity with uncharged soluble particles, and in case of metallic particles, via redox reactions. Following the path laid by Garrison Sposito and Werner Stumm, 52 PhD students and postdocs, half male half female from 23 different countries, contributed to defining these mechanisms, both at the molecular- and field- level.

The same nanoparticles may enter the human body by inhalation, ingestion or uptake by foot skin. Once internalized, they are taken up by human defense system, namely epithelial cells or macrophages into endosomes. Their toxicity can then be purely physical, as in the case of silver nanowire or asbestos fiber puncturing the endosomal membrane, or chemical through various mechanisms. Surface atoms may be oxidized into Fe bodies, to counter Fenton effect, or into Ag_2S insoluble surface layer to counter Ag^+ ion toxicity. If further taken by endolysosomes, negatively charged nanoparticles (with permanent structural charge like montmorillonite, or with low ZPC variable charge minerals like halloysite or silica) can electrostatically attract, or covalently bind positively charged phospholipid molecules that constitute the phagolysosome membrane, leading to their enhanced permeability. These events lead to NLRP3 inflammasome activation and ultimately tissue inflammation causing silicosis, an old disease now affecting kitchen countertop « artificial stone” workers, or podoconiosis, a tropical neglected disease of 4 million bare-foot poor farmers in the East African Rift.