Interaction of *Phaseolus vulgaris* plants with U(VI): Release of root exudates and their impact on the U(VI) speciation

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The safety assessment of radioactive contaminated sites and potential repositories for high-level radioactive waste necessitates the consideration of the release of radionuclides (RNs) into the groundwater and their subsequent transport into the soil, where they can be taken up by plants. Consequently, RNs may enter the human food chain, which poses a significant risk to human health. In the context of plant biology, RNs are non-essential elements that have the capacity to induce changes in various physiological processes, developmental stages, and metabolic pathways. In order to protect themselves from stress, plants release root exudates into the rhizosphere. Furthermore, root exudates have been demonstrated to play a pivotal role in shaping bacterial communities and facilitating nutrient uptake. It is vital to consider the role of root exudates in modulating the bioavailability of RNs by altering their speciation.

The present study investigates the effects of uranium (U) on the crop plant *Phaseolus vulgaris* (bush bean) cultivated in hydroponic solution. The time-dependent bioassociation of U(VI) with the plants is studied as a function of the U concentration using inductively coupled plasma mass spectrometry, whilst the U(VI) speciation in hydroponic solution is studied by time-resolved laser-induced fluorescence spectroscopy (TRLFS). Furthermore, the release of root exudates by *P. vulgaris* plants is studied to understand their impact on the U speciation. In order to achieve this objective, root exudates that are released into the hydroponic solution in the presence and absence of U are isolated, enriched by solid phase extraction and analyzed by high performance liquid chromatography or non-target screening analysis in cooperation with AFIN-TS GmbH.

P. vulgaris plants were exposed for 72 h to 20 or 200 µM U(VI) in phosphate-reduced, half-concentrated Hoagland medium. The bioassociation of U to *P. vulgaris* plants is time- and concentration-dependent. The majority of U was accumulated in the roots, resulting in phenotypic adaptations in both roots and leaves. Thermodynamic calculations of the U(VI) speciation in the medium demonstrated that a range of U(VI) species (including U(VI) sulfate, hydroxo and carbonate complexes) can be anticipated within the studied pH range of 5 to 7. Following a 72-hour exposure of the plants to 20 or 200 µM, three U(VI) species were detected in the medium by TRLFS. One of these species was assigned to the $(UO_2)_2(CO_3)_3^{4-}$ complex, while another was found to be a $(UO_2)_x(OH)_y^{2x-y}$ complex. The third species, whose proportion increased with increasing exposure time, is hypothesized to be a U(VI) complex with a root exudate. However, further research is required to elucidate the identity of this complex and its potential influence on the migration behavior of U and its bioavailability. In the presence of U(VI), *P. vulgaris* roots excreted a greater number of metabolites than in its absence. Indications have been found that the roots of these plants release glutamate as well as organic acids, e.g., citric, malic, succinic, and formic acids.

This work contributes to the process understanding of the interaction of U with plants, which is important for the improvement of radioecological models for the assessment of the RN behavior in the environment.

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