Preface

Atomic nuclei which are not stable but decay by emission of highly energetic radiation are called radionuclides. They are omnipresent in nature, some of them with half-lives exceeding the age of the solar system. Amongst these are, e.g., potassium-40, uranium-238, uranium-235, and thorium-232. Uranium is found in many types of soil and rocks (concentrations ranging from 0.003 ppm in meteorites to 120 ppm in phosphate rock). In addition, there are shorter lived radionuclides produced by natural processes such as interaction of cosmic radiation with the earth's atmosphere. Carbon-14, beryllium-10, and tritium are examples. Human activities such as nuclear weapon's testing in the 1960s, accidents involving nuclear material (military and peaceful use of nuclear power), lost and orphan sources from, e.g. medical use add to the radioactive inventory. Further sources are mining activities. Any matter originating from deep underground may contain considerable amounts of natural radioactive matter (NORM). For instance, the production of oil, gas, or phosphate fertilizers goes hand in hand with the release of considerable amounts of uranium and decay products. Enhanced radiation levels from tailing of these uses are called TENORM (technically enhanced NORM). Also, regenerative energies are not free from radiation risks. Geothermal water used for energy production may contain high levels of radium from the uranium and thorium decay series' accumulating in filters and scales.

Once radionuclides are deposited on the soil surface, they eventually are incorporated into the soil structure, taken up by plants and, via the food chain, enter animals, and also humans. A 75 kg human contains approximately 9,000 Bq of natural radioactivity in his body, mainly due to K-40 and C-14. Some organs such as the thyroid gland and also certain plants may enrich radionuclides, as is known for seaweed, enriching iodine by a factor $>10.000\ L\ Kg^{-1}$. During the course of evolution cells learned to repair damages caused by the ionizing radiation emitted from radioactive decay (alpha, beta or gamma radiation) and the damages caused by secondary species generated from ionizing radiation such as free oxygen radicals (ROS). As a rule of thumb organisms are the more sensitive to radiation the higher their DNA content is. However, at too high radiation levels even simple organisms and cells will suffer and finally the total organism will be damaged or die. While damage from the ionizing radiation to the cells DNA is most important at high dose the chemical toxicity of many radioactive isotopes plays an important role. Uranium, thorium, plutonium, and lead, to name just a few, are heavy metals. In these cases, stress to cells due to chemical toxicity adds to effects of ionizing radiation.

Like heavy metals, radionuclides cannot be naturally or synthetically degraded. Therefore, radionuclides become a risk factor to public health when exposed and/ or deposited in soil and water.

Being sessile in nature, plants are exposed to radionuclides which are released and disseminated into the environment as dry or wet deposition on soil or water. Both routine and accidental incorporation of nuclear wastes in the environment cause radionuclides swallowing, where soil to plant transfer of such materials take place. However, uptake of the radionuclides by plants depends upon several factors including mode of interaction with the materials and physiological characteristics of the species and factors like concentrations, bioavailability, and mobility of radionuclides in surface and subsurface geologic systems. The concentration, mobility, and bioavailability of radionuclides depend upon the quality, quantity, and the rate of release of radionuclides present at the source; different hydrological factors, such as dispersion, advection, and dilution; and geochemical processes, like complexation at aqueous phase, pH, solid/liquid distribution coefficient, reduction/oxidation (redox), adsorption/desorption and ion exchange, precipitation/dissolution, diffusion, colloid-facilitated transport, exchangeable potassium ion distribution, anion exclusion and organic matter contents. Absorption and distribution of the contamination in plants may take place either through direct (exposures at aerial organs) or indirect (through root systems in soil related contamination) routes, which varies considerably in different plant species especially in case of long-lived radionuclides. Furthermore, biological activity or physical changes in the soil properties/texture (like drying and subsequent cracking of soils) and colloid-facilitated transport may augment the mobility and/or affectivity of certain radionuclides Plant tolerance to metals depends largely on plant efficiency in uptake, translocation, and further sequestration of metals in specialized tissues or in trichomes and cell organelles. Metals which are complexed and sequestered in cellular structures become unavailable for translocation to the shoot. Metal binding to the cell wall is not the only plant mechanism responsible for metal immobilization into roots and subsequent inhibition of ion translocation to the shoot. The vacuole is generally considered to be the main storage site for metals in yeast and plant cells and there is evidence that phytochelatin—metal complexes are pumped into the vacuole in plants.

Though radionuclide uptake into plants and consequently into the food chain is generally undesired. A very effective and even selective uptake of certain elements by plants can, however, be even helpful in remediating contaminated soils. This concept is known as phytoremediation. Phytoremediation of radionuclides has many advantages over the traditional treatments. Firstly, in phytoremediation the soil is treated in situ, which does not cause further disruption to the soil dynamics. Secondly, once plants are established, they remain for consecutive harvests to continually remove the contaminants. Lastly but not least, phytoremediation reduces the time workers are exposed to the radionuclides. Finally, phytoremediation can be used as a long term treatment that can provide an affordable way to restore radionuclide contaminated areas. For phytoremediation of radionuclides to be successful, a few criteria have to be met. The most important is that the radionuclides be spread throughout a huge area and be present in very low-level concentrations. The radionuclides must be bioavailable in water/soil solution for plants to up take them into roots. The plants themselves must also be tolerant of the radionuclides when they are accumulated into their biomass. The best plants for phytoremediation are those that have an extensive root system and adequate above-ground biomass.

When plants are exposed to ionizing radiation, molecular and cellular effects are induced directly through energy transfers to macromolecules or indirectly through a water radiolytic reaction producing reactive oxygen species (ROS). By energy transfer from the radiation field to plant tissue, ionizing radiation can directly induce DNA strand breaks, lipid oxidation, or enzyme denaturation. Besides directly damaging macromolecules, potentially toxic ROS can be generated during radiolysis of water, indirectly inducing cellular damage. As ROS are also produced under natural metabolism and also function as signalling molecules regulating normal growth, development, and stress responses, plants also possess an antioxidative defense system comprising enzymes (e.g., superoxide dismutase (SOD) and catalase (CAT)) and metabolites (e.g., ascorbate and glutathione) to regulate the amount of ROS in cells. Plant tolerance mechanisms require the coordination of complex physiological and biochemical processes, including changes in global gene expression. Plants employ various strategies to cope with the toxic effects of radionuclides like metals or metalloids.

Resistance to radionuclides stress can be achieved by "avoidance" when plants are able to restrict metal uptake, or by "tolerance" when plants survive in the presence of high internal metal concentration. Avoidance involves reducing the concentration of metal entering the cell by extracellular precipitation, biosorption to cell walls, reduced uptake, or increased efflux. In a second type of situation, radionuclides are intracellularly chelated through the synthesis of amino acids, organic acids, glutathione (GSH), or metal-binding ligands such as metallothioneins (MTs), phytochelatins (PCs), compartmentation within vacuoles, and upregulation of the antioxidant defense and glyoxalase systems to counter the deleterious effects caused by ROS.

It is an intriguing question whether the toxicity effect induced by heavy metals was the result (at least partially) of signalling pathways evolving the action of the formed substances, or parallel direct metal action and signalling pathways. The molecular mechanisms of signal transduction pathways in higher plant cells are essential to vital processes such as hormone and light perception, growth, development, stress resistance, and nutrient uptake from soil and water. Heavy metals interfere with cell signalling pathways. In fact, it might be hypothesized that metals-induced deregulation of signaling events significantly participates in the metal toxicity response, as well as in damage development.

The main purpose of the present book is to focus on the mechanistic (microscopic) understanding of radionuclide uptake by plants from contaminated soils, both, in order to understand the risks originating from plant uptake and the benefits by potential use for phytoremediation.

The key features of the book are related to the radionuclide toxicity in plants and how the radioactive materials are taken up by plants and cope up from their toxic responses. Some chapters deal with how soil classification affects the radionuclide uptake in plants. Other chapters focus on natural plant selection, speciation of actinides, kinetic modeling, and some case studies on cesium and strontium after radiation accident. Overall, the information compiled in this book will bring in-depth knowledge and advancement in the field of radionuclide toxicity and their remediation through plants in recent years.

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Hannover, Germany

Dharmendra Kumar Gupta
Clemens Walther

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