

Preface

Radioactive Cs (^{137}Cs) is of special concern due to its high radioactivity and long half-life (30.2 years). Cesium has 40 isotopes, more than any other chemical element, with Cs-133 as the only naturally occurring and stable isotope. Testing of nuclear weapons and accidents at both military and civil nuclear facilities led to a large-scale release of radioactive Cs isotopes (Cs-134 and Cs-137) into the environment. ^{137}Cs is a ^{235}U fission product of high yield; ^{134}Cs is an activation product. Cs is a very volatile element and distributes fast after release. Hence, ^{134}Cs and ^{137}Cs contribute a major part to the radiation dose to population and workers. The ^{137}Cs release from the Chernobyl accident (8.5×10^{16} Bq) amounts to ca 10 % of the ^{137}Cs released by atmospheric nuclear weapons testing (1×10^{18} Bq) in the 1960s; the accident at Fukushima Daiichi Nuclear Power plant added another ca 1×10^{16} Bq. The Cs^+ ion is rather easily taken up by plants, animals, and humans due to its chemical similarity with K^+ causing internal exposure. On the other hand, the 661 keV gamma line of its short-lived $^{137\text{m}}\text{Ba}$ daughter causes external radiation exposure, both from gamma submersion and radiation of ground deposition.

The Fukushima Daiichi Nuclear Power Plant (FDNPP) accident led to the discharge of a large quantity of radioactivity into the environment. A total of nearly 9×10^{17} Bq of radionuclides was released in the environment and distributed into an area of 30 km around the power plant. From the FDNPP, radioactive Cs released into the air was estimated at 10^{16} Bq for ^{134}Cs and ^{137}Cs each; it was also reported that ca. 5×10^{15} Bq each of ^{134}Cs and ^{137}Cs were released into the ocean.

There is no doubt that ionizing radiation from radioactive elements can cause several adverse health effects on exposed populations. Several reports showed that the fate of ^{134}Cs and ^{137}Cs derived from the nuclear accident fallout and associated radiological hazards are mainly dependent on their movement in surface soils. Hence, the pathways from contaminated soils via plant uptake and into the human food chain must be understood. Radiocesium is quite soluble, but is strongly adsorbed on soil clays and resists leaching through soils. Cs also behaves similarly to potassium and sodium in terrestrial ecosystems. Potassium generally enters cells through passages and high-affinity transporters, and not all of them show the same permeability for Cs^+ and Na^+ or the same pH or Ca^{2+} regulation. Inward and outward

rectifying K^+ channels show a restricted permeability to Cs^+ and also are highly selective for K^+ over Na^+ .

Plant uptake is the major pathway for the migration of radiocesium from the soil to the human diet. Two major regulatory mechanisms are involved in maintaining K^+ homeostasis, i.e., K^+ flow across the plasma membrane and utilization of vacuolar K^+ reserve. The role of K^+ in enzyme stimulation and protein biosynthesis is based on its high and steady concentration in the cytoplasm.

Even though there are some resemblances in the chemistry of K and Cs, there are numerous differences between the two alkali metals. For example, Cs has a much higher atomic weight and ionic radius than potassium. It is known that the K regime and pH affect the activity of K^+ transporters, and the interaction between K^+ and Na^+ uptake is also well known. Apart from that, it is well known that Ca^{2+} stimulates K^+ uptake in terrestrial plants. In fact, it has been proven that Ca^{2+} stimulates Cs uptake in terrestrial plants and that the K^+ regime affects Cs uptake rates in some grasses. However, voltage-insensitive monovalent-cation channels have been described recently in some plant cells which are permeable to a range of monovalent cations, including K^+ , Cs^+ , and Na^+ and which are inhibited by extracellular Ca^{2+} . High-affinity K^+ transporters are considered the main way by which Cs enters into plants. Molecular studies have exposed that some transporters demonstrated poor perception between K^+ , Cs^+ , and Na^+ which has been shown to reduce K^+ uptake through them. It seems also that these transporters could carry K^+ coupled with the entrance of protons, which has been generally considered the mechanism for the high-affinity K^+ transports in plants.

The soil to plant transfer factor (TF) is an important descriptive parameter that quantifies the uptake of radionuclides into plants and is a valuable tool to estimate dose to the population through ingestion. There are many studies regarding the TF values for ^{137}Cs performed for a specific site. They prove that a single TF for a certain RN – plant couple does not appropriately describe the complicated chemistry involved. In practice, several reasons are proposed to alter the degree of Cs accumulation in plants such as plant species/cultivars, Ca^{2+} levels, plant-associated microorganisms, and Cs location in the soil as well as atmospheric CO_2 levels. In an experiment with sagebrush, wheatgrass, or rabbitbrush it was clear that Cs-137 had a minimum activity in the leaves of the three vegetation species, but increased in the stem and roots; this may be an indication of rapid translocation of ^{137}Cs through the plant physiologic arrangement. There are some experimental confirmations which prove that soluble Cs is transferred directly from foliage surfaces into vegetal materials. It is observed that radiocesium is relocated within the trees by its radioactivity appearing oil leaves, which had developed in few weeks or months after contamination (in the case of the Chernobyl accident).

Plants generally accumulate radionuclides by two principal mechanisms: (1) direct deposition from the atmosphere and (2) root uptake. Reducing the amount of Cs-polluted soils and water is an urgent task following an accident. It is necessary now to develop a technique for solubilizing Cs from soil matrix. River waters, ponds, and sea as well riverbanks are also polluted by Cs. Radioactive Cs has been reported to tightly bind to fine soil particles in water and sediment at narrow depth.

Radioactive Cs is exceptionally tough to remove from the sediment particles and needs to be treated with extremely strong acid for re-solubilizing. Many native bio-remediation methods have employed on terrestrial plants to reduce radionuclides from the environment after the Chernobyl accident in 1986. The accumulation of radioactive Cs into terrestrial plants such as tea, rice, sunflower, and tomato has been reported. In a study, it was reported that *Helianthus Annuus* absorbed up to 150 µg of Cs in 100 h, whereas a *Vetiveria zizanoides* absorbed 61 % of ^{137}Cs in 168 h from Chernobyl accident radio-polluted water. It is also reported that brown alga (*Laminaria digitata*) adsorbed higher than 80 % ^{134}Cs when the membrane was phosphorylated artificially under high pH conditions.

In existing exposure situations on Cs-contaminated sites, there is a need to remove radioactive Cs from the human habitat. One promising possibility is phytoremediation. However, the accumulation capacity as well as the absorption and the accumulation mechanism of Cs in plants must be studied to choose appropriate plants. In terrestrial plants, Cs is mainly taken up by roots and then translocated to the leaf and stem through the xylem vessel. In rice and sunflower, Cs is mainly distributed to young leaves. In *Arabidopsis thaliana*, Cs mostly accumulates in rosette leaves. Several physiological experiments have demonstrated that the mechanism of Cs absorption via roots is similar to that of K. Through aerial deposition, Cs accumulation in the leaves may disturb the basic physiological functions of plants. The first observed reaction in the Cs-treated plants is decreased stomatal opening. The control function of stomata in respect to photosynthetic CO_2 assimilation and transpiration was modified by the presence of Cs. In an experiment, it was noticed that decreased stomatal opening limits transpiration and uptake of water by roots, but photosynthetic CO_2 incorporation did not change during short-term contact to CsCl. Stomatal closure in the presence of Cs may be a result of a reduction in osmotic potential (due to Cs accumulation in vacuoles), the role of Ca^{2+} and K^+ in the regulation of stomatal opening, or disturbance of the signal transduction pathway that is already demonstrated by several researchers. In most cases, possibly Cs inhibits the channels responsible for K^+ transport into guard cells, which influence reduced stomatal opening.

The most noteworthy features of this book are related to how cesium is released in the environment and its translocation from soil to plants and lastly to animals and human. Chapters 1–5 deal with the bioavailability of cesium in the environment and its translocation via soil to plants. Chapters 6–14 focus on the effective half-life of cesium in plants and how different cultivars are responding in the accumulation of cesium; some chapters focus on cesium impact on single cell to higher plants and also on remediation measures and transfer factors. However, the information compiled in the volume will bring in-depth knowledge of cesium uptake and translocation and its toxicity in plants after the Chernobyl and Fukushima accidents.

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Gupta, D.K.; Walther, C. (Eds.)

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