Review for Remediation Technology of Radiocesium-Contaminated Soil

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1. Introduction

Serious environmental contamination with radionuclides resulted from the Fukushima Daiichi nuclear accident in Japan, and a very large amount of soil (~28 million m^3) in a wide area became contaminated [1]. In addition to this critical accident, unintended leakages of radioactive substances from various nuclear facilities have also contaminated the environment, and most of the radio-contaminated soils are subject to low-level wastes [2]. Remediation of radio-contaminated soil has been attempted with various techniques, such as soil washing, phytoremediation, thermal treatment and electroremediation. Although considerable progress has been made in the development of soil remediation techniques for some radionuclides such as U and Co, the removal of radioactive cesium from soil has been relatively inefficient or has required high energy consumption owing to the strong and irreversible interaction of cesium with 2:1 clay minerals in the soil [3].

Therefore, this study was investigate the remediation technologies applicable to soils contaminated with radioactive cesium. Various soil remediation techniques were classified into soil washing, phytoremediation, thermal treatment and electroremediation. These principles and processing of various techniques were analyzed.

2. Remediation technology of radiocesium-contaminated soil

2.1 Soil washing

Soil washing is one of the most common industrial treatments for non-radioactively contaminated soils, and the soil washing process was also demonstrated for treatment of U, Ra, Th, Sr, and Cs contaminated soils. Soil washing generally uses the wet particle size separation because radionuclides have greatest affinity for particles having the highest surface area/volume ratios, such as silts and clays. During the wet separation with washing, the scrubbing action generally removes surface contaminations from the large soil particles such as sand and gravel. The fine soil particles can be separated further in a sedimentation tank, sometimes with the help of a flocculating agent. The output streams of the soil washing process include clean granular soil particles, contaminated fine soil particles, and washing solutions.

Effectiveness of soil washing process is affected by properties of contaminants and soil components. Soil washing is effective only if radionuclides can readily be desorbed from large soil fractions, and contaminated soils optimally contain less than 25% of silt and clays. To improve the removal efficiency of contaminants from soils, surfactants, acids, or solvents can be added to the washing solutions.

At a site in Texas, soil washing combined with ion exchange reduced uranium concentrations in soil from an average of 70 ppm to 20.7 ppm [4]. At the pilot plant demonstration at the Monclair/West Orange Radium Superfund site in New Jersey (USA), 323,000 cubic yards ($246,942 m^3) of soil contaminated with Ra-226, U-235, U-238, and Th-230 were treated over a period of 23 months. Contaminated soil volumes were reduced by 54% and contamination levels were reduced to 5 pCi/g. Soil washing treatment at sites in New Jersey and Tennessee reduced the mass of contaminated soils by 64 and 70% respectively. The process reduced Th-232 concentrations from 18.1 pCi/g to <5 pCi/g at the New Jersey site, and reduced Cs-137 levels from 160 pCi/g to <50 pCi/g at the Tennessee site [5].

2.2 Electrokinetic remediation

Electrokinetic (EK) remediation is an electro-chemical extraction process that can be separate and extract radionuclides from saturated or unsaturated soils. It is performed by applying a low voltage direct current across electrode pairs on each side of the contaminated soil mass. This current mobilizes ions and charged compounds to move towards the electrodes. The dissolved ionic species including radionuclides move toward the opposite-charged electrode at a rate which depends on the local potential gradient (this transport mechanism is called electromigration). Also, the extraction of metals from soil is enhanced by an acidic condition that develops around the anode and by movement of the pore fluid in response to the electric potential difference which is called electroosmosis.

The primary advantage of the EK technique is that in-situ remediation can be accomplished without soil excavation. This in situ process inherently reduces the secondary waste generation, the transport process, and the cost associated with soil excavation, transport, and disposal. The effectiveness, however, is reduced in moisture contents less than 10 percent and where there is interference to electrical conductivity [6,7].

2.3 Thermal desorption

Heat treatment technology is a technique to increase cesium desorption by exposure contaminated soil to high temperature and inducing vaporization or interlayer expansion through pyrolysis. In addition, it has an increasing efficiency by high activity of desorbent, and expansion of interlayer between contaminated soils due to high temperature. However, the heat treatment technique is effective for purifying cesium contaminated soil, but it requires a large amount of energy compared to other treatment techniques and has a high treatment cost. Therefore, heat treatment can be used to maximize the effect of using it with other treatments than with arbitrary treatments.

2.4 Phytoremediation

Phytoremediation is a process that uses plants to remove contaminants in soil. The mechanisms of phytoremediation applicable to solid media include phytoextraction, phytodegradation, and phytostabilization. Because radionuclides including cesium cannot be biodegraded, the main mechanism applicable to remediation of radionuclides is phytoextraction.

Phytoextraction is the uptake of contaminants by plant roots and the accumulation of contaminants into plant shoots and leaves. The plants are subsequently harvested from the growing area, dried, and disposed. Phytoextraction was pilot-tested at Brookhaven National Laboratory to remove low levels of cesium and strontium from soil. Phytoextraction has also been tested in the remediation of cesium-contaminated soil at Argonne National Laboratory West in Idaho [8].

3. Conclusions

Soil contamination by cesium is a worldwide problem, therefore effective remediation approaches are necessary. A number of remediation techniques are used for effective remediation of cesium contaminated sites. In this review, we compared the principles and processing of various remediation techniques generally used to clean-up contaminated soils. However, there are some considerations for soil remediation. Considering the recent contamination of radioactive substances in wide area soil like the Fukushima accident, we must be able to process large amounts of contaminated soil quickly. Also, it must be able to perform the decontamination work in wide area. In this respect, it is necessary to apply a cleaning solution that can reduce secondary waste by the soil washing, and to develop a high performance adsorbent and to reduce the generation of secondary waste.

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