Remediation Measures for Radioactively Contaminated Areas

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Editors

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Foreword

It is my great pleasure and honour to introduce this timely new multiauthored monograph *Remediation Measures of Radioactively Contaminated Areas*, edited by Drs. D. K. Gupta and A. Voronina.

The book *Remediation Measures for Radioactively Contaminated Area*s deals with some specific topical issues related to the recent developments and requirements concerning the safety and protection of the population against radiation exposure due to radionuclides released from areas that were contaminated during the past due to uranium mining and processing or other nuclear activities. It is well known that radiation protection standards and criteria have been constantly geared toward minimizing the impact of radioactively contaminated areas on the human environment. These aims have led to some stricter requirements to ensure adequate protection of the population in terms of their radiation exposure in order to satisfy the present dose limits and reference levels. To meet those requirements, some remediation actions have to be carried out in excessively radioactively contaminated areas, taking into account the latest approaches and recommendations of such expert bodies as the International Commission on Radiological Protection (ICRP) or the International Atomic Energy Agency (IAEA).

The ICRP has recommended the relevant derived levels, which should be applied within different exposure situations. In the past, when the standards for protection were not as strict as they are today, in those areas where nuclear activities such as uranium mining and processing were carried out or where nuclear accidents and other nuclear activities were undertaken, different potential pathways of radionuclides that could cause exposure to people must be taken into account. The situation obviously calls for some remediation actions, which can bring the exposure to the population affected in line with the present safety standards. This book demonstrates some procedures aimed at the reduction of this contamination and their consequences in terms of the potential exposure of humans.

The recommended remediation measures and the assessment of their efficiency rely on the latest general ICRP recommendations (ICRP 2007), which define existing exposure situations, such as situations resulting from sources that already existed when a decision to control them was taken. These recommendations have been recently followed and upgraded in the new International Basic Safety Standards compiled by the IAEA, which defines the situations of exposure due to residual radioactive material associated with past practices that were not subject to regulatory control or that remain after an emergency exposure situation. The latter circumstances are commonly referred to as legacies. As a result of evolving standards and/or because new information can come to light about past activities, new forms of legacy sites continue to be recognized, including sites associated with the processing and the use of naturally occurring radioactive material (NORM).

The IAEA, an autonomous organization under the UN, possesses world-class expertise in the safe and peaceful use of nuclear technologies; its safety standards provide a system of fundamental principles and reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from the harmful effects of ionizing radiation (Copplestone et al. 2016). The IAEA safety standards have been developed for all types of nuclear facilities and activities, including radioactive waste management, the decommissioning of nuclear facilities, and environmental remediation. These standards are aimed at reducing radiation exposure from contaminated soil and groundwater and surface water, which may result from activities such as the mining and processing of uranium or the release of radioactive substances to the environment after a nuclear or radiological emergency. The generation of radioactive materials may also arise from some non-nuclear industries, such as oil and gas production, in which exploration and mining activities can increase the potential for exposure due to an excess in naturally occurring radioactive material.

In accordance with the IAEA (Amano 2016), there are four major elements that need to be considered in environmental remediation:

1. Determining the levels of radiation exposure to people that result from the contamination.
2. Reducing radiation doses and risks, making the best use of the available financial, technical, and labor resources.
3. Returning a site to the conditions that existed before the event that caused the contamination. This may not be necessary and is often not easily achievable anyway.
4. In many cases, the main driver for remediation is the public perception of the risks and benefits of undertaking the cleanup activity. In such situations, the overall well-being of the local community is an important factor in determining the planned final state of the site.

The 14 chapters of the book address and discuss various aspects relevant to remediation actions, including the use of some specific technological procedures whose goal is to identify and reduce the impact of radioactively contaminated areas on the exposed population by the decommissioning and environmental remediation measures implemented following the current international standards and best practice.

It is hoped that the book will serve its purpose and will be a good source of relevant information about the recent developments related to methods and techniques being used to reliably treat radioactively contaminated areas.

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Preface

Environmental cleanup or remediation denotes to reduce environmental contamination including decontamination of radioactive soil or water. The purpose of remediation is not just to clean radiation sources but also to protect humans, animals, and the environment against any probable harmful effects from ionizing radiation (such as decrease of doses of external and internal irradiation due to consuming radioactive contaminated drinking water and food) as well as to return radioactive contaminated lands to farming use (IAEA).

Radioactive pollution may be defined as "the land in which the radioactivity levels are above the ubiquitous natural and artificial background that is typical of the area in which the land is located." The universal artificial background is taken to include radioactivity from atmospheric testing of nuclear weapons in the 1950s and 1960s, fallout from the Chernobyl and Fukushima accident, and radioactivity resulting from effluent discharges from distant nuclear amenities. As places contaminated by artificial and natural radionuclides or even exposures of natural origin may give upsurge to the requirement for environmental remediation, remediation can only start once a harmony on the necessity to reduce existing or future exposures to ionizing radiation (IAEA). In all cases, the actual work, i.e., adopting certain environmental remediation actions, is always a case specific decision.

Atmosphere, hydrosphere, and soils are the media of initial contamination by radionuclides. Among them, the atmosphere may be a medium of radionuclides transfer to hydrosphere and soil. Depending on the conditions of radionuclides release and transfer, these radionuclides may present in the environmental objects in various species; this will condition the method of rehabilitation measures.

The elementary routes controlling movement of radionuclides (and other trace components) in soil comprise convective conveyance by flowing water, spreading caused by spatial dissimilarities of convection velocities, diffusive crusade within the fluid, and sometimes physicochemical exchanges with soil matrix (Walther and Gupta 2015). After deposition of radionuclides on the soil surface, relocation and movement of these radionuclide in soil depends basically on the soil properties, i.e., pH, texture, interchangeable calcium and potassium, and also on organic matter

(Gupta and Walther 2017), and later these fused radionuclides mixed soil ultimately enter into the soil edifice and taken up by plants via food chain and finally relocating to animals and also to humans (Gupta and Walther 2014). In most cases, mobility of radionuclides for relocation from adulterated land to humans and other organisms is primarily via plant root uptake and transfer to groundwater, which is fundamentally determined by the physicochemical aspects inducing the circulation of radionuclides between the solid and solution phases of soil. The uptake of most components by plant roots occurs mainly through soil solution. The important exchanges of any chemical species in solution, which can influence its mobility in soils and ultimate root uptake, include charge interactions, complexation, and precipitation responses with other element species. Till now radionuclides that have been recognized as relevant to assessments of polluted land are: ^{3}H; ^{14}C; ^{55}Fe; ^{60}Co; ^{63}Ni; ^{90}Sr; ^{99}Tc; ^{129}I; $^{134,137}Cs$; ^{226}Ra; ^{232}Th; $^{235,238}U$; ^{241}Am; and $^{238,239,240,241,242}Pu$.

There are numerous approaches present nowadays, which are useful in remediation of radioactively contaminated areas, and henceforth commonly used methods include deep plowing, addition of fertilizes, ameliorants, and sorption-active materials as well as some environmental biotechnology methods, i.e., transgenic plants and bacteria. After Chernobyl (1986) and Fukushima (2011) accidents, various native bioremediation (phytoremediation) approaches have been employed on terrestrial plants to reduce radionuclides from soil environment. Terrestrial plants commonly accumulate radioactivity by two foremost mechanisms: (1) direct deposition from the atmosphere and (2) root uptake. The transfer factor (TF) is significant expressive parameters that measures the uptake of radionuclides from soil to plants and are valuable devices toward assessment of quantity to the population through ingestion (Gupta and Walther 2016). The total absorption of the radionuclide per unit dry mass in the plants (Bq kg^{-1}) resulting by the one in the soil (also given in Bq kg^{-1}). When any radioactively contaminated land is being remediated with the aim of returning for agricultural use, procedures for decreasing radionuclide transference from soil to vegetation are obligatory (Voronina et al. 2015).

At present, plenty of remediation tools are in existence but officials often tend to value proven expertise; in some cases, the existing expertise are not suitable to accomplish the anticipated goals and further developments are required. For the sustainability of nuclear energy, modern nuclear facilities and operations are designed in a way that also take into account the end of the operation life cycle. In this way, the requirement for extensive environmental remediation activities are minimized (IAEA).

This book focuses mainly on the broad overview of reviews on a number of original publications on remediation strategies mainly after Chernobyl and Fukushima nuclear power plant accidents with some case studies showing the latest technological developments and future trends for affected area decontamination. The key features of this book are related to the radionuclide toxicity in soil and its possible remediation technologies and strategies.

Chapter 1 presents a sound review of the current approaches following the decommissioning of nuclear installations, including a summary of different remediation methods recommended for dealing with radioactive pollutants in water and soil media carried out after decommissioning nuclear facilities worldwide.

The following chapter (Chap. 2) deals with the physicochemical methods used to treat radioactively contaminated sites, with special emphasis on the use of soil washing, soil flushing, and electrokinetic approaches.

The sorption method as a prospective technique for the rehabilitation of radioactively contaminated lands, including the decontamination of natural waters and soils from radionuclides and the decrease of radionuclide transfer into agricultural vegetation, is discussed in Chap. 3.

Chapter 4 focuses attention on presenting the theory of concurrent sorption as an instrument for predicting the conditions for desorption of radionuclides, with special emphasis on removing strontium from contaminated solid-water systems.

Applications of biological, chemical, and nanosorption methods in remediation of metal wastes are discussed in Chap. 5. The method described presents a recent technique, where nanoparticles, nanocomposites, core/shell nanoparticles, as well as nanotubes are employed as adsorbents for the removal, transformation, sorption, and detection of all types of pollutants, including noxious radioactive wastes from soil, air, and water.

The potential of biochar as a measure for decreasing the bioavailability of Cs-137 in soil is a topic discussed in Chap. 6. The chapter focuses on the assessment of the possibility of the use of biochar (the biomass which has undergone pyrolysis processing) and soil-improving additives and their potential for decreasing the transfer of cesium-137 to crop production.

Chapter 7 presents a discussion of the large-scale contamination of agricultural lands that resulted from global fallout and accidents in the Southern Urals (PA "Mayak," 1957) and Chernobyl NPP (1986), including the development, testing, and application of remediation measures proposed to prevent the entrance of Sr-90 into the human diet through soil.

The use of bioremediation/phytoremediation techniques for the rehabilitation of radioactively contaminated soil is described in Chap. 8. Available studies demonstrate that these techniques, combined with other chemical or physically based strategies, have the potential to be used inexpensively and effectively in the restoration of contaminated environments.

Chapter 9 describes biological methods for the decontamination of radioactively contaminated areas. Attention is paid especially to phytoremediation of the environment using plants. These processes can potentially be used for the bioremediation of radioactively contaminated areas.

Chapter 10 presents some prospective uses of modified sorbents based on various supports (nonwoven filtering fabrics, aluminosilicates) for the decontamination of natural water with various salt content being contaminated by natural and anthropogenic radionuclides such as cesium, strontium, uranium, radium, lead, bismuth, and thorium.

The problems related to the treatment of radioactive waste after the rehabilitation of contaminated areas are the topics presented in Chap. 11, which also describes some modern approaches to the decontamination and deactivation solutions of radioactively contaminated soils, the treatment of radioactive biological materials and spent sorption materials, as well as the disposal of radioactive waste after rehabilitation.

The next chapter (Chap. 12) concentrates on modeling the effect of the mechanical remediation of dose rates above the surface of contaminated soil by radiocesium. Some examples of applying this strategy are illustrated as well.

Chap. 13 reflects specific practical experience in applying remediation methods at the Semipalatinsk test site (in Kazakhstan). In addition, some results of remedial efficiency in radioactively contaminated territory by plowing soil are documented.

The final Chap. 14 introduces the basic elements of radiation protection requirements needed for the assessment of the impact of remediation measures in radioactively contaminated areas. Relevant quantities and units for the quantification of radiation exposure of persons due to the presence of radioactive contamination are also outlined.

In whole, the information collected in this book will bring in-depth understanding and expansion of knowledge in the field of radionuclide toxicity and their possible remediation. Dr. Dharmendra K. Gupta and Dr. Anna Voronina individually acknowledge the authors for contributing with their precious time, knowledge, and interest to bring this book into the present shape.

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