Chapter 11
New Decontamination Methods for Parks and Other Areas in Which Radionuclides Have Accumulated

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Abstract Activities to remove radionuclides in the wake of the Fukushima Daiichi nuclear accident were unprecedented in nature and required the utmost urgency. The methods employed generally involved pulling plants out by the roots. Arguably, however, such drastic measures were unavoidable to achieve the paramount objective of reducing radiation dosage, thus avoiding irradiation of residents and ensuring safety. However, pulling plants out by the roots can have extremely harmful consequences. Not least of these is the volume of waste (trunks, branches, leaves, roots, soil, etc.) generated and the way in which the waste is disposed. In addition, the land is stripped bare by the decontamination process, compromising the various functional benefits the plants had previously provided to the community. Our approach to decontaminating trees and wooded areas is aimed at improving the effectiveness and efficiency of the decontamination process by utilizing current landscape architecture knowledge and techniques.

Keywords Decontamination • Parks • Grass fields • Wooded area • Radiation blocking

11.1 Introduction

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11.2 Decontamination of Greenery: Basic Policy and Specific Initiatives

The authors’ fundamental approach toward the decontamination of green areas is to fully utilize landscape architecture knowledge and techniques to achieve the dual objectives of decontaminating the area while preserving greenery and generating as little waste as possible. To achieve this, we must first ascertain the distribution of radionuclide and determine the parts of the greenery that need to be removed. Then we can implement effective decontamination measures as required, including cropping or pruning away the contaminated sections. Furthermore, we aim to renew and revitalize plants through these processes, improving their appearance, health, and functionality compared to their pre-decontamination state.

In this chapter we describe the outcomes of a series of practical experiments and field tests we conducted to develop techniques to use at contaminated sites. The four decontamination methods we have devised to date are (1) landscape architecture-based lawn decontamination and renewal (a method of decontaminating Japanese lawn grasses by removing the grass protruding above ground while preserving the underground stolons and root system, followed by application of topdressing and fertilizer to renew and revitalize the grass); (2) radiation blocking (a method of reducing radiation dosage by covering contaminated areas such as lawns with a thick top layer of grass or another material, without removing the existing plant life); (3) radiation capture (a method of preventing recontamination and secondary contamination in risk areas by using plants such as mosses to capture and absorb radionuclide); and (4) radiation reduction (a method of absorbing and partially removing radionuclides from the soil using greenery such as grasses that can regrow after mowing).

11.3 Landscape Architecture-Based Lawn Decontamination and Renewal Method

Rather than pulling out warm-climate grasses such as mascarene grass and noshiba (Zoysia japonica Steud.) at the roots, only the parts in which radionuclides have accumulated are removed: this includes removing the stems and leaves, matted cut grass clippings and erect stems accumulated on the soil surface, and stolons protruding above ground. Alternatively, we remove the top 1–2 cm of soil while preserving the underground stolons and root system. Subsequently, topsoil and fertilizer are applied to promote new growth, renewing and revitalizing the grass. For
extensive areas of lawn such as green spaces in parks, large vehicle-mounted turf strippers (Fig. 11.1) or sod cutters can be used to perform the deep mowing process, whereas domestic string trimmers or lawnmowers can be used for smaller areas such as home lawns.

The major benefit of this method is that the total cost is approximately one quarter that of methods that involve stripping the grass by its roots and replanting following decontamination. Furthermore, the amount of waste generated is reduced by half.

11.4 Radiation Blocking

In this method, rather than stripping off the contaminated grass layer, the surface is covered with either another thick layer of grass (turf cut approximately 10 cm deep) or a thick layer of sprayed vegetative base material. The latter method involves using a specialized compressed air device to spray areas such as bedrock or embankments made of sprayed mortar that lack a substrate to support plant life. Such surfaces are sprayed to a depth of 5 cm or more with a mixture of organic vegetative base material (a combination of bark compost, peat moss, etc.) combined with fertilizer (slow-acting) and bonding agent (polymer resin, or sometimes bentonite or other substances to increase the radiation-blocking effect), into which grass seed such as tall fescue is mixed. The main advantage of this method is that it generates no waste and can be used in any environment.
11.5 Radiation Capture

Radiation capture is a method whereby cesium or other radionuclides are proactively captured and absorbed to prevent recontamination or secondary contamination caused by wider dispersal. Mosses grown in sheet form are spread on structures such as building walls or water channels to capture radiation in the air or rainwater. Alternatively, aquatic plants are grown at the water’s edge to prevent contamination of lakes and marshes from inflow of earth and sand containing the radionuclide. Our attention focused on mosses in particular as related studies had shown that they have a strong tendency to accumulate radionuclides. We decided to turn this capacity to good use, and came up with this method of using mosses to capture radiation.

The new method requires cultivated sheets of moss to be fixed onto flat or slanted rooftops, or the walls of buildings. The sheets are also attached to areas where radionuclides tend to accumulate, such as drain holes and gutters, and can be wrapped around the trunks of trees at the roadside or in gardens and parks. The method utilizes the capacity of moss to proactively capture radionuclide in the air and rainwater. After a certain time, the sheets attached to or wrapped around an object are removed, and new sheets applied; this helps prevent secondary contamination and recontamination, and also lowers the ambient radiation dose to a certain extent.

Next, we studied eight major types of aquatic plants grown in the exhibition garden at the city of Koriyama’s Ouse Park, measuring and comparing their ability to adsorb and accumulate radionuclide. This approach enabled us to evaluate their potential for use as radiation capture agents in waterside areas. As a result, we found that horsetail and Japanese rush plants contained a high concentration of radioactive material. In addition, their relative ease of propagation and rapid growth make them highly effective candidates for use as radiation capture agents in waterside areas.

11.6 Radiation Reduction (Absorption and Removal of Radionuclides in Soil Through Phytoremediation by Greening Plants)

We set out to determine what characteristics make plants potential candidates for use in absorbing radionuclide. According to our own current list of requirements, a candidate plant should (a) be evergreen, (b) be capable of propagation from seed, (c) have a high germination rate, (d) have easily obtainable seeds, (e) have stalks and leaves that cover a large ground area, (f) be able to withstand poor soil conditions, (g) be hardy and able to withstand neglect, (h) be able to help maintain or improve soil fertility, (i) be able to withstand harsh heat, (j) be fire resistant, (k) not have flowers that attract birds or insects (to prevent the spread of radiation via these agents), (l) have absorptive roots concentrated near the soil surface, (m) be able to absorb and accumulate radioactivity year after year, (n) have foliage that does not protrude too far from the ground and does not generate much bulk when trimmed and collected, and (o) be an energy-generating plant that can be used as biomass.
From the authors’ observations so far, ideal candidate grasses include dwarf tall fescue and Bermuda grass, which have conventionally been used to green sloping areas and to create evergreen lawns and can quickly regrow after being cut. We are currently conducting cultivation tests to determine their ability to absorb cesium.

11.7 Decontamination of Trees

11.7.1 Mechanism by Which Trees and Wooded Areas Are Contaminated

Radionuclides (isotopes) scattered aerially in the event of a nuclear accident contaminate trees and woodland areas through a variety of routes and mechanisms. This contamination occurs partly through direct routes whereby radiation enters the tree after attaching to the leaves and branches of the tree crown or to the trunk, and it also occurs partly through indirect routes whereby radiation is deposited on or within the soil and is subsequently absorbed by the plant. Trees are either evergreen or deciduous, and the mode of contamination varies accordingly.

In the case of the Fukushima nuclear accident, the trees were irradiated around the middle of March, so deciduous trees were still at the winter bud stage and had not yet developed new shoots. Thus, the new leaves that subsequently developed were not exposed directly to the radioactive fallout. Nonetheless, it has been reported that the fallen leaves showed a high concentration of radionuclide that year. It is therefore hypothesized that radionuclide that attached to the winter buds may have transferred directly to the new leaves that subsequently developed, and that some of the radiation absorbed by the roots from the soil may also have transferred to the leaves.

Meanwhile, in evergreen trees it is possible for radionuclides to be detected in new leaves that grow on the irradiated branches later in the same year. Evidence of this was provided when radionuclides such as cesium were detected in tea leaves grown in some parts of Shizuoka’s tea-growing areas when the first tea was picked in 2011, leading to a temporary ban on shipments. These observations imply that it may be possible for radionuclide attached to the old leaves to be absorbed into the plant then transferred internally to the new leaves. The same phenomenon has, moreover, been observed in fruit, with shipment of persimmons being banned because of detection of radiation. This finding suggests that the same mechanism may apply in other tree varieties.

11.7.2 Overall Approach to Decontamination of Trees and Wooded Areas

Our approach to decontaminating trees and wooded areas is aimed at improving the effectiveness and efficiency of the decontamination process by utilizing current landscape architecture knowledge and techniques. This enables us to develop methods
based on a sound understanding of the mechanisms and modes of contamination involved, obviating the need to uproot trees or plants. During this process we aim to aggressively prune overgrown branches and leaves that have not been properly tended to improve the health and vitality of the individual trees and wooded areas as a whole without negatively impacting their appearance.

### 11.7.3 Specific Methods for Decontamination of Trees

To reduce the tree’s total radiation dosage, the overall volume of branches and leaves should be reduced significantly by cutting back or thinning out, without harming the tree’s shape or appearance. Any radiation that attaches to the surface soil surrounding the tree and its roots must be thoroughly removed.

The process involves (1) pruning to remove all leaves and branches in the treetop portion of the tree crown (i.e., that year’s branches), (2) pruning to thin out leaves and branches in the tree crown to around one third of their original volume, (3) thoroughly washing the branches and trunk of the tree crown with a high-pressure water blaster, or peeling/grinding the bark, (4) removing all fallen leaves under the tree crown, and (5) removing the top 2–3 cm of soil under the tree crown. In steps (4) and (5), the aim is also to collect the radionuclide contained in the water used for blasting and the peeled/ground bark. Following initial decontamination, the situation should be reassessed every 1 to 2 years, with any of steps (1) to (5) repeated as necessary as maintenance work in response to subsequent changes in the tree’s radiation dosage and growth.

### 11.7.4 Decontamination of Bark by High-Pressure Water Blasting or Peeling/Grinding

As are the trees’ leaves, the trunks and branches are also contaminated with radionuclide and, naturally, they also require decontamination. However, decontamination methods differ according to the condition of the bark covering the tree surface. Moreover, the condition of the bark varies dramatically depending on the species of tree and also changes as the tree ages.

Although smooth bark is comparatively simple to decontaminate with a high-pressure water blaster, many species of trees have horizontal or vertical wrinkles or cracks in their outer layer of rough bark (which comprises cork or dead phloem tissue that protects the living tissue inside). There may be radionuclide inside these wrinkles or cracks, and as water blasting alone is insufficient to completely remove such contamination, in some cases measures such as peeling/grinding of the outer bark are required. However, peeling/grinding the outer bark raises the risk of damaging the internal tissue, and a careful approach is therefore necessary. The
Fukushima Agricultural Technology Centre has already demonstrated that peeling/grinding the outer (rough) bark of fruit varieties such as grape vines, *nashi* (Asian pear), apple, and persimmon trees proved successful in reducing contamination to a significant extent.

### 11.8 Forest Decontamination Initiatives

When decontaminating forests, as a general rule areas within 20 m of populated (residential) areas should be treated, either by removing fallen leaves from the forest floor, cutting undergrowth, and removing the $A_0$ (litter) layer, or by radiation blocking using the thick-base spray method. In other areas, the radiation dose should gradually be reduced by thinning suppressed (overcrowded) trees and controlling density to ensure that the forest is preserved and further cultivated, in addition to caring for and maintaining the forest in other ways, such as by cutting undergrowth.

As part of our research, we attempted to quantify the efficacy of decontamination measures in the Japanese cedar groves and broad-leaved deciduous wooded areas of Ouse Park in Koriyama, Fukushima Prefecture. We removed fallen leaves, forest floor undergrowth, and the $A_0$ (litter) layer, then studied the rate of decline in the radiation dose and analyzed the distribution of the total radiation dose using a gamma camera. The foregoing measures were found to reduce radiation levels by 10–20% compared to the levels before decontamination. In light of the fact that felling trees to decontaminate forest areas leads to loss of the functions provided by greenery and generates problems of the large volume of waste generated, there is a need for detailed site studies into the extent to which thorough cleaning of the forest floor is effective in decontamination.

### 11.9 Establishing Monitoring Methods to Conduct Scientific and Economically Efficient Decontamination

Two years on from the nuclear accident, the dynamics of radioactive contamination are gradually being understood. For the decontamination process to be performed effectively, efficiently, and without waste, and to accurately assess the resulting benefits, radioactive contamination should ideally be mapped in a visible format to give an overview of the situation. This method would allow all parties to share a common understanding of the radiation dose preceding decontamination, and also serve as a decision-making tool when deciding which areas to prioritize, making it easy to check how effective the decontamination process has been and whether there is any unevenness in results. To study the feasibility of this method, we are currently evaluating the performance of gamma cameras and radiation monitors. For some time
we have also been using a bio-imaging analyzer to conduct tests at the laboratory level to identify which parts of plants are contaminated. An alternative application for this research could be in managing the safety of temporary and “pre-temporary” storage sites for radioactive waste generated from the decontamination process.

For both decontamination case studies and post-decontamination surveys our aim is to use gamma cameras to map radiation doses in a visible format, as well as radiation monitors to make the measurement process more efficient. Accordingly, we tried out new cameras and monitors and evaluated their performance in on-site tests at parkland green spaces in the cities of Koriyama in Fukushima Prefecture and Matsudo in Chiba Prefecture. As a result of these tests, we found that measurement by gamma camera was an extremely effective tool in mapping the radiation dose visibly, particularly when it came to detecting contamination hot spots in wooded and grassy areas. However, these cameras are extremely expensive, and to obtain accurate measurements several experienced staff are required to operate them and analyze the data. There are, moreover, several other hurdles to using gamma cameras at decontamination sites, including the fact that the measurement process itself takes a significant amount of time. The radiation monitors, on the other hand, are lightweight and portable, and can provide real-time measurements in series as the operator walks around. These monitors proved to be highly effective measurement devices for detecting pre-decontamination hotspots and evaluating post-decontamination benefits.

11.10 Measuring the Directional Contributions to the Ambient Radiation Dose to Perform Effective Follow-Up Decontamination

In the grounds of some residential buildings, ambient radiation doses fail to reduce significantly despite decontamination, which is often caused by the effect of radiation from nearby woodland areas or fields. In such cases, the planning of effective follow-up decontamination measures would be facilitated if we knew the extent to which radiation originating from a certain direction was contributing to the total dose at a particular site. To this end, Michinori Mogi, who collaborated with the authors on this project, developed a collimator capable of dividing a space into six portions. The directional contributions to a radiation dose can be measured by rotating the open face.

11.10.1 Overview of the Apparatus

We created a collimator made of lead 3 cm thick that is capable of housing the entire detection unit of an NaI scintillation spectrometer (AT6101 NaI(Tl), ∅40×40 mm). The only opening was a solid angle $2/3\pi$ (sr) from the center of the detection unit,
and rays of radiation could reach the detection unit from the direction of the opening uninterrupted. By rotating this open face, the contributions to the total radiation dose from six different directions could be measured.

### 11.10.2 Sample Measurements

We took measurements in the village of Iitate, Fukushima Prefecture, behind a house that backed onto a hill slope. The hill slope began just 2 m from the house, and we selected a point at a height of 1 m above the middle of the flat area to take measurements. We suspected that the hill slope was contributing significantly to the radiation dose (Fig. 11.2).

First, we measured the background dose by using a 3-cm-thick lead sheet to completely cover the opening of the collimator, which was pointed upward. Compared to an ambient dose of 0.65 μSv/h when the opening was unobscured, the background dose was 0.051 μSv/h. Next, we measured the dose from six different directions, starting from the direction facing the house wall. Measurements were taken before and after obscuring the hill face with sprayed soil (radiation blocking) and decontaminating the flat area by removing the top layer of soil. Measurement results are shown in Fig. 11.3. The sum of the dosage rates minus the background dose from all six directions matched the total unobscured ambient dosage rate minus the background dose to within a 10 % margin of error. Looking at the directional contributions before decontamination, the contribution from the ground below the measurement point was largest, comprising 30 % of the total dose. The contributions from the hill face and the north and south directions comprising the flat area each accounted for 20 %. The contributions from the upward direction and the direction of the house were small, at less than 6 %. Following decontamination and other measures, the overall ambient dose declined to 54 % of the original figure, with the largest reductions (to 37–54 %) witnessed from the directions of the flat area.

![Fig. 11.2](image-url)  
**Fig. 11.2** Point at which directional contributions to ambient radiation dose were measured
ground surface where the top layer of soil had been removed. If the house direction and the upward direction are excluded, it is evident that post-decontamination radiation dosages from the other four directions were all lower and their contributions to the dosage at the measurement point became more evenly balanced.

11.10.3 In Conclusion

In the past, we had only an intuitive understanding of directional contributions to radiation doses, but this study enabled us to ascertain contribution ratios quantitatively using a collimator. We believe that application of this method will allow the sources and directions of the strongest radiation doses to be identified, enabling appropriate countermeasures to be taken.

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