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Author(s)	Kaname Miyahara, Takayuki Tokizawa and Shinichi Nakayama
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Decontamination Pilot Projects: Building a Knowledge Base for Fukushima Environmental Remediation

Kaname Miyahara, Takayuki Tokizawa and Shinichi Nakayama
Fukushima Environmental Safety Center, Headquarters of Fukushima Partnership Operations,
Japan Atomic Energy Agency (JAEA),
2-2-2, Uchisaiwai-cho, Chiyoda-ku, Tokyo, 100-8577, Japan

ABSTRACT

After the Fukushima Dai-ichi nuclear accident, Japan Atomic Energy Agency (JAEA) was chosen by the Government to conduct decontamination pilot projects at selected sites in the contaminated area of Fukushima. Despite tight boundary conditions in terms of timescale and resources, the projects provide a good basis for developing recommendations on how to assure clean-up efficiency and worker safety and reduce time, cost, subsequent waste management and environmental impact. The results of the project can be summarised in terms of site characterisation and data interpretation, clean-up and waste minimisation and storage.

INTRODUCTION

The damage to the Fukushima Dai-ichi nuclear power plant (NPP) by the Great Tohoku earthquake and tsunami resulted in considerable radioactive contamination, both on- and off-site of NPP. After decay of shorter-lived nuclides, the contamination is now dominated by radiocaesium ($^{134}, ^{137}\text{Cs}$), which is the focus for clean-up actions. Caesium tends to bind strongly to soil, especially clays. Dose rates are generally low with a few exceptional locations, resulting predominantly from external gamma irradiation and from continual reduction by washoff and soil mixing.

After the accident, staged clean-up of contaminated areas was initiated – first in populated areas (especially sensitive areas such as schools and playgrounds) and then, following stabilisation of the reactors and decay of shorter-lived nuclides, extending into evacuated zones.

The overarching “Special Measures” laws to manage radioactive contamination from this incident and establish an overall policy for decontamination were promulgated on 30th August and 11th November 2011. These specified responsibility for conducting a range of decontamination pilot projects to examine applicability of clean-up technologies to the higher levels of contamination within the evacuated zone. Based on such projects, the Government will develop the technical basis for efficient and effective clean-up technologies, assuring worker safety, establishing a regional remediation plan and advancing to stepwise implementation of decontamination, with a special focus on reducing dose rates and allowing evacuees to return to re-establish their normal lifestyles as quickly as possible.

Japan Atomic Energy Agency (JAEA) was chosen by the Government to conduct decontamination pilot projects at model sites. The first project included 2 residential sites with lower contamination levels, which ran from August 2011 until March 2012. The second project was implemented from September 2011 until June 2012 at 16 sites in 11 municipalities, including highly contaminated sites in evacuated zones. Despite tight boundary conditions in terms of timescale and resources, the decontamination pilot projects provided a good basis for developing recommendations on how to assure clean-up efficiency and worker safety and reduce

time, cost, subsequent waste management and environmental impact.

The regional decontamination presently being initiated must be well planned, rigorously implemented and clearly presented to all stakeholders. However, decontamination on such a regional scale in a highly populated region has never been attempted before. Main challenges to implement full-scale decontamination are lack of both real-world examples and also experience for planning and implementing decontamination technology appropriate to Japanese boundary conditions. Therefore, the decontamination pilot projects played a key role to support drafting of guidelines and manuals that can be used as a source of reference by the national government, local municipalities and the contractors performing regional decontamination. This paper discusses this application of the decontamination pilot projects, focusing on those carried out in the evacuated zones.

DEVELOPMENT OF THE PILOT PROJECTS

The evacuated zone is quite typical of Northeast Japan, *i.e.*, comprising a narrow coastal plain and valleys leading into a spine of densely wooded mountains. Along the coast and in the plain, the population density is relatively high with agriculture being an important industry. In the more mountainous areas, population is mainly confined to narrow valleys although, even here, agriculture is important, as is tourism.

The locations of the sites selected for the decontamination pilot projects, specific constituents and features requiring clean-up, the level of contamination and project site grouping are summarised in Figure 1. As can be seen, these are representative of the challenges that will be faced in the regional remediation and allow for different approaches to remediation to be compared. Further, the locations include both urban and rural areas in different terrain (mountainous, hilly, plain). JAEA selected 3 contractor Joint Ventures to carry out the work, while JAEA managed, supervised and evaluated the overall program. Documentation of the decontamination pilot projects has been published in Japanese [1, 2].

Procedure

A tailored remediation plan was developed for each of the demonstration sites selected. The plan involves initial characterisation of the distribution of contamination, setting priorities and deciding details of remediation techniques to be implemented (*e.g.* extent of surface soil removal based on depth profiles of radiocaesium concentration). Such analysis also allowed first estimates of the volume and radioactivity of wastes to be expected and hence the requirements for temporary storage facilities to be determined. The remediation plan also explicitly considered operator safety, which involves consideration of both radiological and conventional labour hazards. Further requirements for the remediation plan were to consider minimisation of environmental impact and a process for communication to establishing dialogue with stakeholders.

Following preliminary remediation planning, implementation for each of the demonstration sites proceeded in the following steps:

- Radiation survey before remediation (establish maps of radionuclide distributions; particularly useful to guide remediation planning and determine depth profiles to allow assessment of benefits of different soil remediation approaches)
- Establish remediation implementation plan based on evaluation of radiation survey data
- Apply remedial measures

- Evaluate effectiveness of remedial measures
- Review effectiveness and assess input for remediation guidelines.

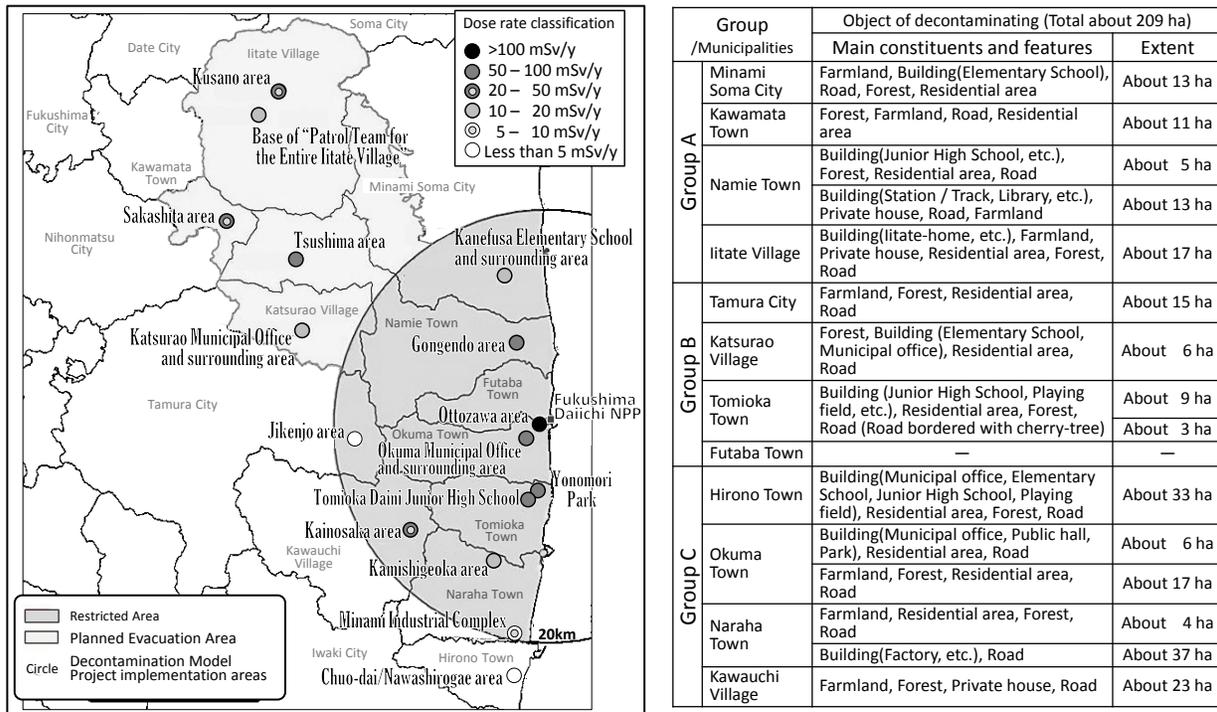


Figure 1. The sites and targets for the decontamination pilot projects

Site characterisation and data interpretation

Measurement approaches for site characterisation involved both modification of existing technology and development of new methods - measuring total dose rate, surface contamination or radiocaesium concentration. When linked to appropriate data loggers, these provided rapid and convenient electronic maps of radiocaesium distributions.

Maps were particularly useful to guide remediation planning. In-situ measurements could be subdivided into 2 broad classes, local dose rate measurements and determination of radiocaesium contamination levels. The former integrates dose rate due to gamma radiation from all sources in the vicinity at a defined height above ground surface (usually 1m or 1cm). To provide more information than a simple integrated dose rate, near-surface measurements (1 cm) were made using GM detectors that are particularly sensitive to betas. All demonstration projects started from pre-existing digital maps and aerial images, which were integrated with any pre-existing radiological survey data (e.g. aerial gamma scans, point measurements) to derive a first conceptual model of initial site contamination. Novel scanning tools developed (incorporated into a remote-controlled helicopter, a buggy or a backpack to facilitate access to the complex terrain involved) could be considered only semi-quantitative, but have proven useful for establishing relative radioactivity distributions and finding hotspots.

Depth profiles of radiocaesium concentration allowed assessment of benefits of different soil remediation approaches. In general, 80% or more of radiocaesium in soil was present within about 5 cm of the topsoil. In dense asphalt pavements, most of radiocaesium was present within about 2 to 3 mm from the surface.

Options of clean-up methods could be assessed using a model to predict effective dose

reduction. Because of the long range of gamma rays in air (the half-distance for ^{137}Cs 0.66-MeV gamma ray in air is about 70 m), assessing the net impact of decontamination on local dose rates is not straightforward. As a guide to planning, therefore, a calculation tool (Calculation system for Decontamination Effect; CDE) has been developed by JAEA (<http://nsed.jaea.go.jp/josen/>; in Japanese only). Basically, this applies a 5-m mesh to the area of interest and for each lattice cell specifies a surface radiocaesium concentration (derived from measured air doses, assuming a continuous flat surface) and the land use. For a given set of specific decontamination factors applied to the different objects in the site, the resultant change in the map of dose rate distribution can be calculated. Although the obtained quantitative output is associated with uncertainties, the model is a first step to assess the consequences of different decontamination strategies on the net dose distribution and hence tailor a general remediation plan to a specific site.

Radioactivity monitoring was continued during remediation actions, to provide feedback on effectiveness and quantify the characteristics of wastes generated. This then led to a more complete survey after remediation to form the basis for assessment of effectiveness of different methods.

In principle, the effectiveness of the entire clean-up operation could be assessed by comparison of dose rates at a number of specified points before and after clean-up. This provided a measure of the dose reduction achieved, but the ratio of before/after (Dose Rate Reduction Factor; DRRF) tended to underestimate effectiveness, as it included a background from the surroundings, which could actually contribute a large percentage of the final measured dose rate.

Measurements with a GM detector were also made before and after remediation of some surfaces. If suitable shielding / collimation was used, the measurement is proportional to the extent of superficial contamination (due to the short range of the betas counted) and, for the case where radiocaesium does not penetrate to any significant depth, the ratio of count rate before/after provides a direct measurement of the decontamination factor.

Reliable measurements must be a basis to assure clean-up efficiency and worker safety. Special care was taken to check the working temperature of detectors, as these are generally assumed to be used within the range of about 0 to 40°C. For measurements below 0°C, which was often encountered at a few sites, recalibration was needed. Measurement biases were observed due to difference of NaI scintillation survey meters with or without energy compensation circuit. Therefore, measured data obtained from the latter survey meters were appropriately corrected.

Clean-up

In each of the selected demonstration sites, decontamination targets were identified and different technologies were applied to specific targets, such as buildings, forest, farmland, etc. Although the majority of the effort involved manual washing and contaminated material removal using conventional technology, methods that might improve clean-up while decreasing volumes of waste were tested (some examples illustrated in Figure 2). To avoid generating secondary contamination, decontamination proceeded from topographically higher locations to lower ones, with clean-up of roads the final step.

Radiation exposure of clean-up workers was continuously monitored by ensuring that all workers wear a cumulative dosimeter and a pocket dosimeter and remained low during the course of the projects and well within the specified dose limit. For example, in the case of highly

contaminated agricultural and residential areas, average exposure dose of clean-up workers is 2.4mSv over 108 days. The atmospheric radioactivity concentrations observed in decontamination work areas of this pilot project were not particularly high. Because the workers wore protective equipment, the internal exposure doses of all workers were below the limit of measurement (1 mSv).

1) Trees and forest

The main decontamination methodology used for forests was simple removal of contaminated material, including undergrowth, fallen leaves, humus/litter layer, topsoil and tree pruning. Removal of leaves was carried out both manually (where vegetation was swept up using rakes) and mechanically, using vacuum suction (small “car-based” and large “lorry-based” vacuums were tested). Reduction of volume using a chipper was important for woody materials, such as bamboo, small trees and pruned branches.

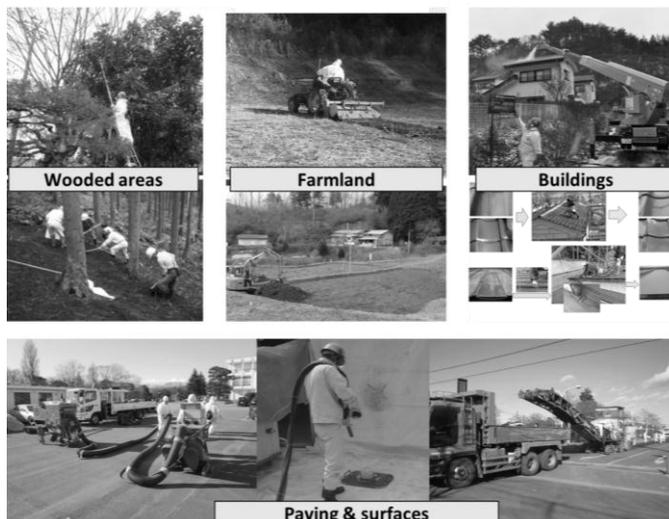


Figure 2. Images of some of the remediation methods used.

2) Farmland

Decontamination methodologies for agricultural land included vegetation removal (manually with a strimmer or mechanically using a grass cutting machine), soil inversion (manually with a spade, mechanically with a small mechanical rotavator or ploughing). Soil removal using a mechanical digger was, in some case, preceded by “soil solidification” using a resin spray.

For a typical example of soil inversion, field vegetation was first harvested using trimmers, followed by deep ploughing to 25-cm depth; this technique inverts the soil profile and greatly decreases dose rate above the ground surface due to shielding by uncontaminated topsoil. An alternative technique for deeper emplacement involved removal, excavation and backfilling: the top 5 cm of soil (containing most, if not all, of the contamination) being removed followed by a further 45 cm of subsoil, the contaminated surface soil is then layered in the hole and covered by uncontaminated material.

3) Buildings

For houses, techniques designed to loosen surface contamination on roofs and walls included manual wiping, cleaning with brushes and high pressure water cleaning (although here care had to be taken to avoid water penetrating roofs). All water used was carefully collected and decontaminated by filtration or ion-exchange before discharge to drainage. The decontaminated water was reused for cleaning in some cases. Although roof tiles are made from diverse materials, with the exception of weathered cementitious roof tiles, these techniques were generally effective for decontamination. A focus for roofs was cleaning gutters, which often represented contamination hotspots.

Large buildings, such as schools and factories, were treated in a similar manner, but novel techniques were tested to clean larger concrete surfaces where simple washing was ineffective.

These included pneumatic shot blasting with either small steel balls or dry ice. Eroded thin layers of the contaminated concrete surface were collected by vacuum for later disposal (with magnetic separation of steel shot for reuse). Both these methods have the advantage of avoiding use of water (and resultant decontamination), but require careful dust management to avoid workers internal exposure as well as careful control of external exposure due to gamma irradiation from resulting waste.

After decontamination of buildings, the surrounding environment was treated. Garden vegetation was cut back, usually by strimming, mowing or clipping, followed by soil turnover or complete removal of soil surface layers if required. Particular attention was paid to removal of hotspots, often found underneath the eaves of roofs or in drains collecting roof runoff. Unpaved surfaces and gravel were generally treated by high-pressure water cleaning and wastewater collected for subsequent treatment.

4) Roads and paved surfaces

Roads were decontaminated using a number of methods, which were generally “lorry based”. Initially roads were sprayed with water with mechanical cleaning by large coarse rotating brushes. Alternative techniques tested for removing contamination from roads and pavements included high pressure water jets, very high pressure water (such as spin jet washing which could erode thin layers of the contaminated surfaces), shot blasting and complete removal of asphalt from roads. In all cases contaminated run-off was collected and pumped into tankers for later treatment or reuse, and any other wastes (especially dust) captured for treatment and/or packaging for storage.

Waste minimisation and waste storage

A specific goal of the demonstration projects was to optimise clean-up procedures in order to reduce waste volumes to the maximum extent possible. For reduction of the volume of soil requiring disposal, the main approach used involved using measured profiles to determine depth of penetration of radiocaesium and then using a technique which removed only the most contaminated material. Indeed, when low-level radiocaesium contamination was limited to near the surface, soil profile inversion variants are effective management options, which produce no waste and reduce radiation dose rate by the natural shielding of uncontaminated soil. At some sites waste was segregated according to its radioactivity level with scan-sorting equipment. In the demonstrations, this equipment was used for excavated soil and farm wastes, which were sorted to allow material with a specific radioactivity less than a reference value to be returned to the excavation site and only that exceeding this level to be packaged for storage.

The large quantity of organic waste being produced was a particular focus for volume reduction. Methods employed for this material included chipping, physical compaction and incineration – both high (> 800 °C) and low temperature (250-400°C) variants. For the latter options, cost and throughput have to be balanced against the volume and radioactivity concentrations in resultant ash.

Wastewater from decontamination activities was either filtered for reuse or pumped into holding tanks for treatment. Treatment methods included ion-exchange and scavenging by co-precipitation, with filtration of resulting fluids and drying of sludges and precipitates. All resulting contaminated solids were placed in flexible plastic containers for storage and purified water released to drains.

In most cases, solid waste was simply placed in flexible plastic containers, labelled and

then transported to a temporary store. These flexible plastic containers have a volume of about 1m³ and are strong enough to be lifted even when full of wet soil. They are impermeable, but cannot be considered gas- or water-tight. They were labelled with either a robust conventional tag or an electronic readable chip, which contains a sample location code, date of packaging, description of contents, estimated radiocaesium content and surface dose rate.

A regulatory constraint on waste management was that all significantly contaminated material had to be placed in temporary storage at the site being remediated. The locations of these storage facilities were selected taking into consideration topography, land use, available areas of land, local government requests and required the explicit agreement of local communities and landowners. Several different design options for such temporary storage, either on the surface or in shallow pits (see figure 3), were developed with the key aim of assuring safety over the required period (defined as lasting not more than 3 years). The details of the design were tailored to the storage site topography, which resulted in design variants for flat areas (on surface or sub-surface) and for sloping sites (inclined and stepped). In all cases, the temporary storage facility included an impermeable base, surface cover and uncontaminated soil backfill to provide shielding. It was not expected to make such structures completely watertight, so drainage due to gravity flow was incorporated in all cases. Drainage was monitored and captured in a water collection tank for any required treatment. Because of the organic waste content, allowance is made also to allow gas venting to ensure pressurisation does not disrupt the engineered barriers.

The temporary storage options implemented during the demonstration sites were designed to meet the guidelines issued by Ministry of the Environment. The facilities at the demonstration sites are being carefully monitored to check performance is maintained and, in case of any problems, appropriate actions will be taken.

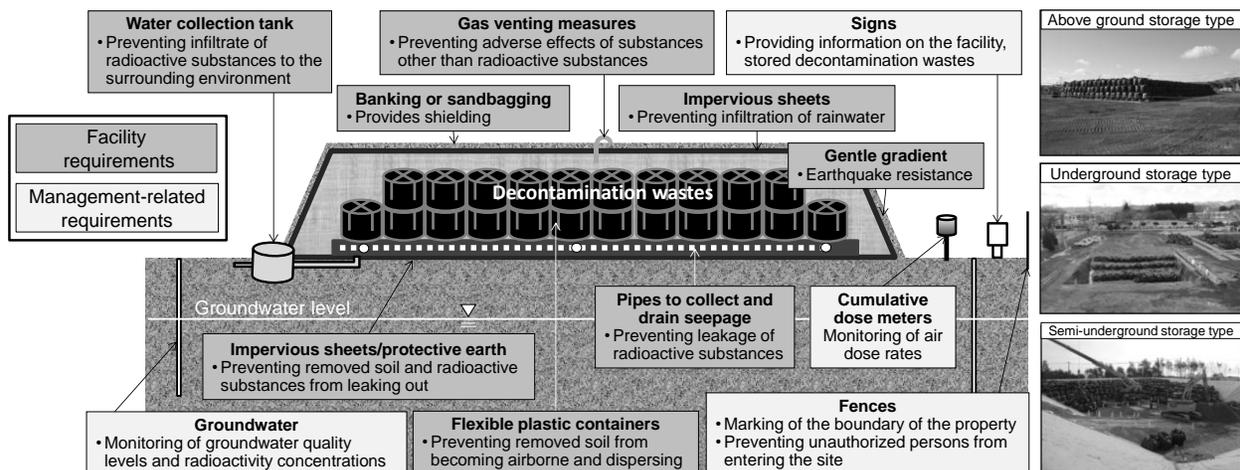


Figure 3. General concept for temporary storage and some illustrative examples

DISCUSSION

Wide area decontamination

The experience gained in the remediation projects has provided valuable input in terms of developing fast and efficient approaches to assessing the relative distribution of radioactivity (or dose rate) in any remediation area. Integration of electronic maps, geographical information

(land use, etc.) and measured radiometric data has worked well. Figure 4 shows an example of results of dose rate reduction by wide area decontamination. Dose reduction here, based on average dose rates in each land use compartment, is between 40% and 80%.

In terms of estimated annual dose reduction to less than the initial evacuation level of 20 mSv/y has been demonstrated for areas with 20 - 30 mSv/y before decontamination. However, this goal could not be assured for areas exceeding 40 mSv/y before decontamination. In case of highly contaminated agricultural and residential areas, the dose rate was decreased by 70 %, but could not be reduced to below 50 mSv/y. In general, the fractional dose rate reduction was smaller in areas of relatively initial low contamination, compared with higher contaminated areas.

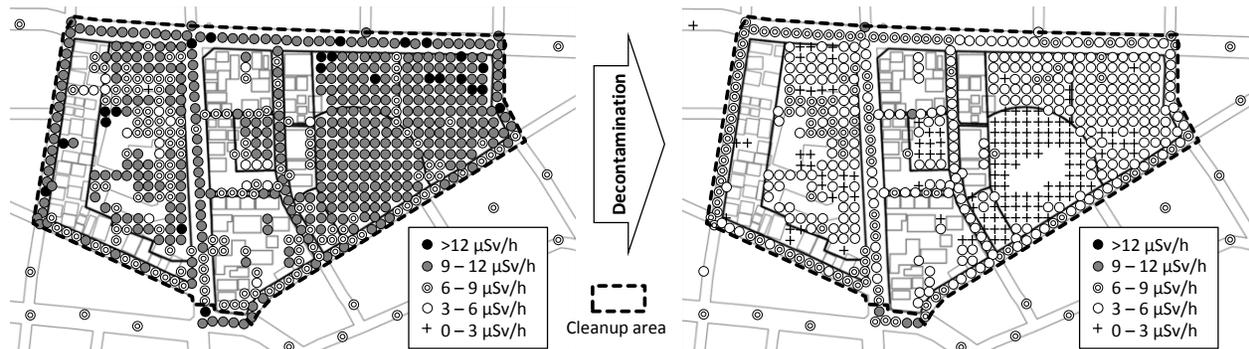


Figure 4. Impact of decontamination on measured doses

Recommended clean-up technologies

To facilitate use in tailoring to specific site conditions, the remediation toolkit requires pros and cons of different methods to be clearly identified. Most of the parameters involved were reasonably easy to assess during demonstration (*e.g.* cost, time and manpower requirements, volume of wastes generated). In principle, the effectiveness of the entire clean-up operation could be assessed by comparison of dose rates at a number of specified points before and after remediation. A pragmatic approach was to carry out remediation actions sequentially and compare dose rates measured at the target object before and after cleaning.

Table 1 shows comparison of forest decontamination methods. Recommended clean-up methods for each land use target were derived by comparing options in terms of dose reduction, speed, cost, waste management and environmental impact. In general, clean-up methods with higher dose reduction resulted in higher cost. For some clean-up methods, however, dose reduction was comparable but cost and/or efficiency was different.

The derived recommended clean-up methods for each land use target are listed in Table 2.

Lessons learned

The demonstration projects have served their primary purpose of development of a knowledge base to support more effective planning and implementation of stepwise regional remediation of the evacuated zone. A range of established, modified and newly developed techniques have been tested under realistic field conditions and their performance characteristics determined. This toolkit covers site characterisation, clean-up and waste storage.

Table 1. Characteristics of different remediation methods for wooded areas.

◎: highly effective; ○: effective; △: moderately effective; ▲: limited effect

Decontamination method	Removal of fallen leaves and humus (on flat ground)	Removal of fallen leaves and humus (on slopes)	Removal of fallen leaves, humus and topsoil (on flat ground)	Trees	
				Trunk washing	Branch trimming in the lower part
Proportions of radioactivity on evergreen trees (as of August - September 2011)	44-84 %			Trunks: 1-3%	Branches and leaves: 14-53%
Percentage dose reduction*	5-90 %	5-90%	20-80%	30-85 %	5-40 %
Volume of decontamination waste generated	0.2-0.9m ³ /m ²	0.2-0.9m ³ /m ²	1-2m ³ /m ²	Small amount	2.7m ³ /m ² (non-reducing waste volume)
Secondary contamination	Does not occur.	Does not occur.	Does not occur.	Occurs. (Soil infiltration of droplet)	Occurs. (Drop branches to forest floor)
Effects on surrounding environments	On slopes, it is necessary to be careful not to cause erosion.				
Cost (JPY)	530/m ²	760/m ²	890/m ²	3,390/tree	580/m ²
Decontamination speed	510 m ² /day (11 persons)	340 m ² /day (11 persons)	220 m ² /day (5 persons)	32 trees/day (4 persons)	150 m ² /day (4 persons)
Applicability	Deciduous forests	◎	◎	○	▲
	Evergreen forests	◎	◎	○	○

*Percentage dose reduction is calculated using the values of surface contamination density measured before and after decontamination. In the case of the branch trimming, the values of air dose rate are used.

Table 2. Comparative assessment of remediation options for different targets

◎ : highly effective, ○ : effective, △ : moderately effective, ▲ : limited effect

Land use classification		Comprehensive evaluation	
Forest		◎Removal of fallen leaves and humus (on flat ground and slopes), ○Removal of fallen leaves, humus and topsoil (on flat ground), ▲Trunk washing, ○Branch trimming in the lower part (evergreen tree)	
Farmland		◎Machine that strips off surface of soils, ○Backhoe (stripping off depth of 5 cm of the soil), ◎Reversal tillage (by tractor and plough), ○Ploughing to replace surface soil with subsoil (by backhoe)	
Residential area	Roof	▲High pressure water, ○Brushing, ○Wiping, ▲Apply a remover	
	Gutter	△High pressure water, ○Wiping	
	Wall	○Brushing	
	Topsoil	○Removal of topsoil	
	Rubble	○Washing of the rubble, ○Removal of the rubble	
	Turf	○Removal of the turf	
	Garden tree	▲Clipping a garden tree	
Interlocking block		△High pressure water	
Large structure	Concrete and Mortar surface		
	△Sanding machine with the dust-collection (Plane which scrapes concrete), ○Ultrahigh pressure water (Over 150Mpa), ○High pressure water (10-20Mpa), ○Iron shot blasting		
	Roof floor	Concrete surface	○High pressure water (including brushing)
		Waterproof coating surface	○High pressure water (including brushing)
Downpipe		○High pressure water(Maximum 50Mpa)	
Playing field		○Strips off surface of soils (Large mower+Sweeper), ○Strips off surface of soils (Road planers), ○Strips off surface of soils(Motor grader), ○Ploughing to replace surface soil with subsoil	
Swimming pool		○High pressure water	
Turf		○turf stripper	
Paved road		▲Road cleaners + Riding style road sweepers, △High pressure water (About 15MPa)+Brushing, △Car of a functional recovery drainage pavement, ○Ultrahigh pressure water (120~240MPa),○Iron shot blasting,○TS road planers	

1) Site characterisation

Although the pilot projects were set up under extreme time pressure, which did not allow optimisation of procedures or standardisation of measurement protocols, short manuals were developed to guide sampling and field measurement and independent quality assurance checks were introduced. Improvements have been identified that will allow establishment of user-friendly sampling and measurement protocols which allow measurement uncertainties to be rigorously measured and minimise measurement biases.

Unlike conventional civil engineering work, it was difficult to visually assess the progress of large-scale decontamination work. For example, when stripping topsoil manually, it was difficult to visually judge if the entire contaminated surface layer had been removed. Therefore, during clean-up, the surface dose rate was often monitored to check the effectiveness of

procedures, particularly during removal of hotspots. Because of the complexity of sites and local movement/storage of wastes, such monitoring requires low background, well-shielded detectors which need to be easily transportable over rough and often soft ground. Some further development of equipment is required here, but technical specifications have been established and conceptual designs illustrated.

2) Clean-up

➤ Forest

For both evergreen and deciduous forests, effective decontamination generally results from removal of leaf litter and humus layers. Cleaning a forest perimeter about 10 m wide at boundaries with living areas gave a significant dose rate reduction (40 to 50%). In the case of dense woods, such as bamboo forests, vacuum suction was efficient for stripping and transport of leaf litter and humus. Special care was needed in the common case of steep slopes, where removal of this cover increases the risk of soil erosion and landslips (the region is regularly exposed to intense rainfall during typhoons). Therefore, in such cases it is necessary to implement measures to reduce soil erosion (such as sandbags or reed mats). The demonstration projects thus provide clear guidelines for wider remediation of forests.

➤ Farmland

More than 80% of radiocaesium in soil is generally found within a depth of about 5cm in the topsoil. Somewhat deeper penetration is found in farmlands that were ploughed just before contamination occurred after the March 11 accident and locally where soil mixing results from biological activity or human actions (*e.g.* tractor wheel ruts). These observations are consistent with Cs being strongly bound to mineral surfaces and hence, to date, “soil washing” approaches have not been attempted – although this might be investigated in the future.

Many different techniques for either soil stripping (possibly with initial solidification or subsequent sorting) or soil profile inversion have been tested in different settings with pros and cons being identified. Deciding between options for a specific site will need to consider not only the local soil Cs profile, but also field size, future agricultural use, desires of the landowner and even weather conditions as different approaches may be appropriate for either wet or cold conditions. Although the demonstration projects provide an extensive knowledge base to support such decisions, incorporation into a user-friendly communication platform will improve future ease of access to this information.

➤ Buildings

A special focus for buildings, especially houses, is cleaning roofs and, especially the hotspots found in gutters, drains and other locations where runoff is captured. Simple manual methods are generally sufficient and, although high pressure water jets can be used, these need to be carefully handled to prevent water penetration of tiled roofs. Porous / weathered cementitious surfaces were trickier, but several methods to remove the thin layer of contaminated material with minimal production of secondary wastes have been tested. Monitoring the effectiveness of decontamination of the surfaces was a challenge that was not completely resolved, but may be handled in the future by improved equipment design (*e.g.* boom-mounted shielded detectors).

➤ Roads

The depth distribution of radiocaesium varied from about 2 to 3 mm for asphalt and dense-graded pavement to about 5 mm in more porous “drainage” paving, which constrains the type of approach used for clean-up. Depending on the required dose rate reduction, potential techniques include high- to ultra-high-pressure jet (up to about 200 MPa), brushing, abrasion and,

as a last resort, complete resurfacing. For all such methods, it is important that all fluids and dust are captured and generated wastes are minimised. It was noted that high-efficiency filtration was just as effective as other water decontamination methods including ion-exchangers and flocculants – again compatible with the assumption of Cs being strongly bound to mineral surfaces. Assessing the effectiveness of less disruptive methods may need to be tested on a case-by-case basis, again requiring effective monitoring of progress but with less difficulty of using existing shielded detectors in this case (can be easily mounted on a wheeled vehicle)

3) Waste handling and storage

The standard flexible plastic containers used to collect and transport “raw” wastes represent a pragmatic and cost-effective approach that is familiar to the contractors involved. This is, however, not equivalent to conditioning and packaging required for waste disposal and hence the temporary stores are considered as short-term measures only (about 3 years), providing time to develop and implement plans for longer-term storage (up to about 30 years) and final disposal. Nevertheless, it is important that these temporary stores provide sufficient radiation shielding and prevent any release of radioactivity into air or groundwater.

The designs of stores are tailored to available sites but all include measures to assure mechanical stability (*e.g.* infilling spaces between containers with sand, graded cover with soil) and prevent releases to groundwater (impermeable base and cap, gravity flow drainage including radiation monitors and catch tanks). Nevertheless, these are simple structures and the contained wastes are labile and vulnerable, in particular, to biodegradation. Gas production may occur and vents are included in the design to avoid pressurisation. Site monitoring also needs to check that structures are not perturbed by external events that can include typhoons, heavy snowfalls, freeze/thaw cycles and earthquakes.

Although stores constructed during the demonstration project have served their initial purpose in terms of concentrating and confining the wastes, their behaviour needs to be continually and comprehensively monitored and, in the event of problems, experience captured is fed back to improve future designs.

4) Informed consent

To obtain the consent from local residents, which are necessary to allow such work to progress, the support from mayors of local municipalities and heads of administrative districts was indispensable. Briefing sessions with communities and use of a clear and simple consent form also helped to facilitate this process. Materials for explaining remediation to stakeholders and providing the basis for establishing dialogue with them have been developed, including plans of remediation and temporary storage and rapid communications on evaluating effectiveness of remedial measures.

Nevertheless, focused efforts are needed to ensure that stakeholders are kept fully informed and encouraged to “buy-into” the work by directly participating in dialogue leading to decision making. During future remediation, an example here is development of a web-based communication platform that allows user-friendly access to the results of the demonstration projects – not just in the form of conventional reports but also using modern media to summarise issues in the form of interactive images, blogs, videos, animations, etc. This platform will be accessible to both computers and smartphones – the latter being very popular in Japan – and will facilitate user feedback and distribution of information via social networks. If successful, this tool could be extended to support the entire regional remediation programme.

CONCLUSIONS AND FUTURE PERSPECTIVE

JAEA demonstration projects have provided a knowledge base including:

- experience and tools for planning, coordinating and implementing efficient, safe and cost-effective remediation programmes,
- an evaluation of the applicability of existing and newly-developed clean-up technology, with an assessment of the pros and cons of different approaches, and
- guidelines for tailoring of projects to the conditions found in different sites.

Practical experience has shown that stakeholder involvement in implementation of clean-up activities is essential. Materials for explaining remediation to stakeholders and providing the basis for establishing dialogue with them have been developed.

During future remediation, experience can be used to constantly update the clean-up knowledge base with the intent of continuous improvement of methodology and toolkits. An advanced communication platform is being implemented to facilitate information exchange between all those involved and, in particular, encourage dialogue with local communities and their involvement in decision-making. Waste management will be a special focus for research and development to support optimisation in terms of both volume reduction and easing/increasing safety of temporary storage, interim storage and eventual final disposal. The regional work will allow displaced populations to return home to normal lifestyles as quickly as possible and provide the knowledge and experience needed for later decontamination of the Fukushima Dai-ichi site.

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