Technical Data

Design, Construction and Monitoring of Temporary Storage Facilities for Removed Contaminants

Hiromitsu SAEGUSA [1], Hironori FUNAKI [1,*], Hiroshi KURIKAMI [1], Yoshiaki SAKAMOTO [1] and Takayuki TOKIZAWA [1]

[1] *Fukushima Environmental Safety Center, Japan Atomic Energy Agency, 1-29 Okitama-cho, Fukushima-shi, Fukushima 960-8034, Japan*

Since the Fukushima Daiichi Nuclear Power Plant Accident caused by the Tohoku Region Pacific Coast Earthquake on March 11, 2011, decontamination work has been conducted in the surrounding environment within the Fukushima Prefecture. Removed contaminants including soil, grass and trees are to be stored safely at temporary storage facilities for several years, after which they will be transferred to a planned interim storage facility. The decontamination pilot project was carried out in both the restricted and planned evacuation areas in order to assess decontamination methods and demonstrate measures for radiation protection of workers. Fourteen temporary storage facilities of different technical specifications were designed and constructed under various topographic conditions and land use. In order to support the design, construction and monitoring of temporary storage facilities for removed contaminants during the full-scale decontamination within the prefecture of Fukushima, technical know-how obtained during the decontamination pilot project has been identified and summarized in this paper.

KEYWORDS: Fukushima Daiichi Nuclear Power Plant Accident, removed contaminants, temporary storage facility, facility requirements, management-related requirements, decontamination pilot project, technical know-how

I. Introduction

A large amount of radioactive material has been released into the environment because of the accident at the Tokyo Electric Power Co. Inc. Fukushima Daiichi Nuclear Power Plant, as a result of the Tohoku Region Pacific Coast Earthquake that occurred on March 11, 2011. The decontamination effort to reduce risks to human health and the living environment is still ongoing in various areas. To carry out the decontamination, the soil, fallen leaves, and vegetation (hereinafter referred to as “removed contaminants”) must be stored safely in a temporary storage yard until being transferred to interim storage facilities [1)].

The Japan Atomic Energy Agency (hereinafter referred to as “JAEA”) has been making use of the RD findings regarding the disposal of radioactive waste, and formulating organizational

* Corresponding author, E-mail: funaki.hironori@jaea.go.jp
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policies to secure the safety of temporary storage yards, construction methods and policies for monitoring after construction, and has been providing technical support regarding site selection, design, etc. of temporary storage for the local governments and residents in the region. Furthermore, our work forms part of the Government-commissioned project “Decontamination Demonstration Projects on Evacuation Areas, etc., for the Fukushima Daiichi Nuclear Power Plant Accident,” and the “Decontamination Demonstrations Projects in the Restricted Area, Planned Evacuation Area, etc.” (hereinafter referred to as “Decontamination Pilot Project”) conducted in eleven municipal government zones designated as restricted zones, etc. This decontamination pilot project mainly involved the regions where a high dose rate was recorded, and where the annual additional exposure dose exceeded 20 mSv, and was aimed at establishing efficient and effective measures for decontamination, etc., and for securing radioactivity protection for workers.

One or two construction locations per municipal government, for a total of fourteen temporary storage yards and storage sites (both hereinafter referred to as “temporary storage yards”) were selected in accordance with the agreed adjustments made between the local governments, the Fukushima decontamination promotion team, and the cabinet support team for the livelihood of disaster victims. As defined, a “site storage place” is a facility for temporarily storing removed contaminants for a certain period until the temporary storage yards are ready. During the selection of construction sites for temporary storage yards, the authors provided advice for site selection under the Fukushima decontamination promotion team, and was involved in the communications, etc. designed to promote understanding among the residents. The selected sites for temporary storage yards represented a wide variety of land use types, such as flat land, national forests in mountainous areas, cultivated land, pastures, and steep valleys.

The authors executed the design, construction, maintenance, and management of the temporary storage yards according to these various conditions.

In this paper, as well as describing the policies for securing the safety of the temporary storage yards for the purpose of contributing to future maintenance, such as full-scale decontamination in accordance with the decontamination guidelines [2] “Edition 4: The Guidelines for Storage of Removed Soils,” we extracted and reported technical know-how (e.g., important points, site selection of types, etc., relevant to each operation) through actual experience in relation to the design, construction, maintenance, and management of temporary storage sites.

II. Fundamental Policies to Secure the Safety of Temporary Storage Yards

The decontamination pilot project was started in November 2011. At the beginning of this project, the design of temporary storage yards was conducted based on fundamental policies for safety, considering case examples of the final disposal site design for municipal solid wastes and industrial wastes [3], case examples of studies regarding fire prevention of combustible disaster wastes [4], case examples of design for safe demonstration testing for the disposal of very low-level concrete waste conducted by JAEA [5], etc. This was necessary because policies for the maintenance/preservation of temporary storage yards have not been formulated by Government. After that, the guidelines on decontamination [2] (hereinafter, this stands for “Edition 4: The Guidelines for Storage of Removed Soils”) were drawn up, and specific measures for the maintenance/restoration of temporary storage yards were presented. Comparison of these showed a general match, but the measures for earthquake resistance proposed in the guidelines on decontamination were not included in the safety policies that we had formulated previously. Therefore, policies for earthquake resistance were added to the fundamental policies for securing safety. An overview of the fundamental policies for securing the safety of temporary storage yards based on the contents of the guidelines on decontamination [2)] is presented below and shown in **Figure 1**.

(a) Radiation shielding and isolation

These are required to prevent the public from being exposed to additional γ-radiation from the removed/concentrated contaminants, to be achieved by covering the facility with soil, etc., to isolate it from the human environment.

(b) Prevention of removed contaminants scattering

To prevent the dispersion of radioactive materials when bringing the removed/concentrated contaminants into the facility, a closeable container will be used, covered during transport.

(c) Prevention of infiltration of rainwater, etc.

Preventing the infiltration of rainwater is essential to avoid the translocation and outflow of soils, vegetation, etc. that may contain contaminants such as radioactive cesium.

(d) Prevention of outflow of removed contaminants and radioactive materials

It is necessary to prevent the contamination of public water and groundwater by soil outflow carrying adhered radioactive cesium, or by the migration of radioactive cesium dissolved in water. For this purpose, countermeasures were implemented to prevent the outflow of removed contaminants and radioactive cesium in the base of the temporary storage yard.

(e) Prevention of influence by components other than radioactive materials

In a separate section where organic substances such as grass and fallen leaves are stored, which may spontaneously combust, a heat accumulation prevention measure was implemented to avoid fires that could ignite from accumulated heat if internal heat generation exceeded balancing heat radiation.

(f) Earthquake resistance, etc.

Measures must be taken for the prevention of damage to shielding, and the prevention of

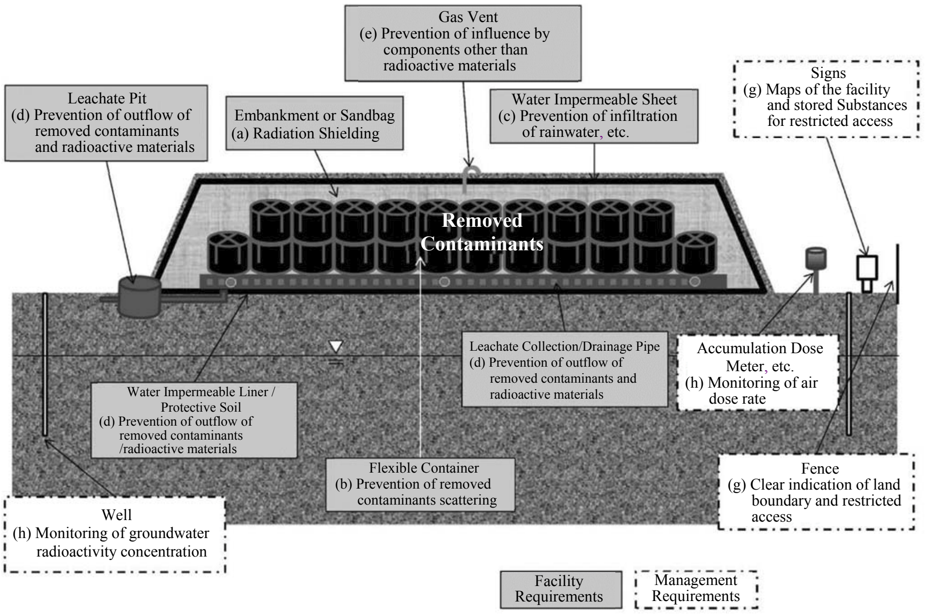


Figure 1 Facility requirements and management-related requirements of a temporary storage facility

outflow of removed contaminants and radioactive materials, such as the collapse of removed contaminant containers and shielded soils during an earthquake.

(g) Restricted access

In addition to implementing other measures to prevent unauthorized entry into the facility by the public, signs must be visibly posted indicating a storage facility for removed radioactive contaminants, and enabling emergency communications.

(h) Radiation monitoring and recovery, etc.

To confirm the safe storage of removed contaminants during and after the transport of removed contaminants, and to check the outflow of radioactive material from the facility, if an abnormality is found attributable to the temporary storage yard, necessary actions will be taken.

(i) Preservation of records

Records will be kept to track the transportation and storage of removed contaminants in temporary storage yards and interim storage facilities, as well as collection sites, which specify the contents and their location in the temporary storage yard, and other relevant factors.

Furthermore, removed contaminants are generally classified into combustible and incombustible materials. Soils, stones, etc. are classified as incombustible materials, while asphalt, vinyl sheets, filters, rubber gloves, vegetation, Tyvec suits, waste cloths, etc., are classified as combustible materials.

III. Case Examples of Design and Construction of Temporary Storage Yards

1. Temporary Storage Yard Type

For sites suggested by local governments for the construction of temporary storage yards, it was decided to investigate the possibility of using a design that satisfies the requirements in Section II, based partly on the type of temporary storage yard, whether above ground, underground, or semi-underground (**Figure 2**). The most important factors are mainly the usable area of the premises with regard to the estimated generated quantity of removed contaminants, the

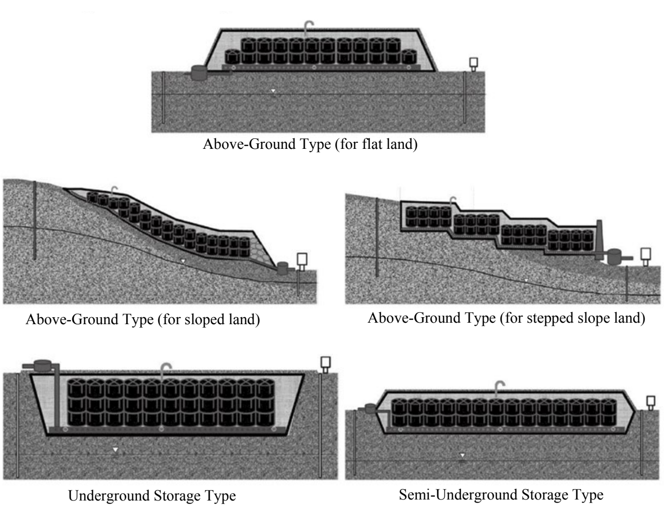


Figure 2 Various types of temporary storage facilities

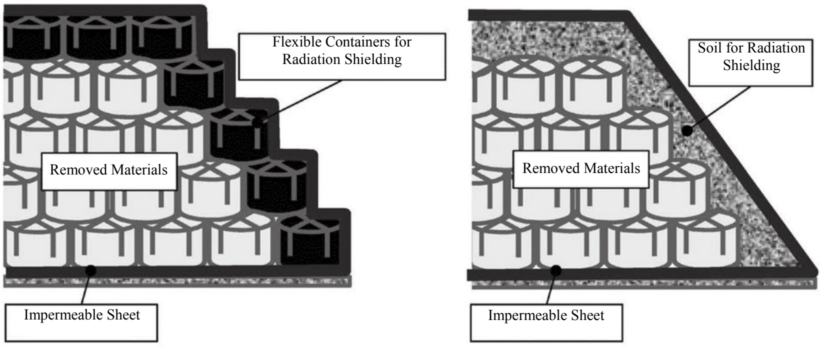
topographical conditions, land use status, and the ground characteristics.

2. Specifications for Facility Requirements

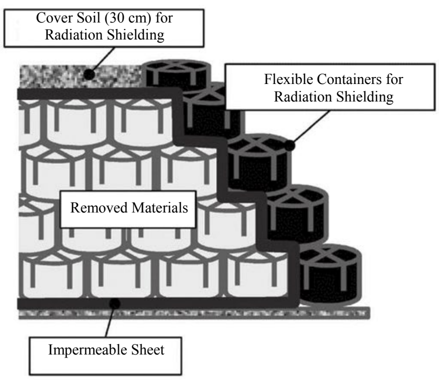
Reasonable specifications were set up for facility requirements considering the wait time until transportation to the interim storage facilities, and the cost effectiveness of the process. Practical specifications according to facility requirements are summarized as follows:

(1) Shielding and isolation

It is possible to shield 98% of γ-rays generated by the removed contaminants with a 30 cm layer of soil, or a 30 cm layer of concrete (such as a wall block)[6]. In the decontamination pilot project, if shielding is required, uncontaminated soil, which is less costly than a concrete retaining wall, was selected as the shielding material. To install the shielding material in either case, uncontaminated soil thicker than 30 cm was used for covering and surrounding the removed contaminants, plus the impermeable sheet mentioned later (**Figure 3(1)**). Alternatively, the removed contaminants were covered with an impermeable sheet, and weatherproof flexible containers were filled with uncontaminated soil (about 1 m wide) (**Figure 3**(**2)**). In the first case, a weatherproof sheet or a light-resistant sheet was placed over the impermeable sheet as an anti-ultraviolet ray measure. The second case focused on protecting the weatherproof sheet from ultraviolet rays and from damage by birds and animals.



(1) Cover the removed materials with soil, then cover all with aimpermeable sheet



(2) Cover the removed material with an impermeable sheet and bury it with covering soil

Figure 3 Conceptual designs of shielding methods

(2) Prevention of removed contaminant dispersion

To prevent the dispersion of removed contaminants when bringing them into a temporary storage yard, the contaminants were carried in flexible containers during transportation. Furthermore, to prevent dispersion when the removed contaminants were taken out at the end of the storage period in the temporary storage yard, flexible containers with a durable lifetime of a several years were used. After transporting the removed contaminants, impermeable sheets and covering soil were used as dispersion prevention measures.

Furthermore, special weatherproof flexible containers were not used because the measures stated in III-2-(3) and item (4) were applied.

(3) Prevention of infiltration of rainwater, etc.

The surface and slope side were covered with an impermeable sheet to prevent the infiltration of rainwater, etc.

(4) Prevention of outflow of removed contaminants and radioactive materials

To prevent the outflow of radioactive cesium in the leachate, an impermeable sheet was laid under the temporary storage yard. To prevent sheet damage due to the roughness of uneven ground, an asphalt-type impermeable sheet was sprayed directly on the ground to allow for plastic deformation after drying. For other locations, an impermeable sheet made of synthetic rubber or synthetic resin materials, or a bentonite impermeable sheet was laid to allow elastic deformation.

When bringing in the removed contaminants, to avoid damage to the impermeable sheet, as well as to lay a protective mat on the impermeable sheet, protective soil was laid between the removed contaminants and the impermeable sheet to adsorb radioactive cesium and inhibit translocation. Furthermore, when heavy machinery was used on the impermeable sheet, protection mat, and protective soil, a covering such as a steel sheet was used to prevent damage. To collect leachate from the removed contaminants, a collection pipe with holes and pits was installed. Moreover, crushed stone, etc., was laid around the pipes with holes to prevent clogging by sand and mud as much as possible.

(5) Prevention of influence except from radioactive materials

For enhanced heat dissipation, and to exhaust heat generated by the decomposition of organic materials, a gas vent pipe was mounted at the top part of the covered contaminants. Furthermore, a separate section in which organic materials could be stored was designed in an area less than 200 m^2 with a height of 2–5 m based on case examples regarding the aforementioned fire prevention of combustible disaster wastes [4]. Furthermore, if separation into several sections was required, and to implement a spacing between sections of at least 2.0 m, sand was prepared for easier fire extinguishing in the event of fire.

3. Construction of Temporary Storage Yards and Placement of Removed Contaminants

(1) Construction of temporary storage yard

The construction of the temporary storage yards began with tree trimming and ground leveling, excavation as necessary, the setting up of a section for storing removed contaminants (building a dam), laying impermeable sheets and leachate drainage pipes, laying protective soil, positioning the removed contaminants, and then laying down the upper impermeable sheets and covering them with soil, regardless of topographical status, land use status, or type of temporary storage yard.

Additionally, equipment such as the collection pit and gas vent pipe, etc., were installed. Furthermore, light-shielding protection mats and fire extinguishing sand were provided in addition to the top impermeable sheets when necessary.

The condition of removed contaminants in above-ground temporary storage yards, (for flat land, slopes, and steep valleys), underground storage types, semi-underground storage types, and the external appearance after completion are shown in **Figure 4**. As seen in these case examples, the design and construction were done in a flexible way in accordance with topographical status and land use status, etc., of each installation site.

Moreover, in spite of the site-to-site differences in scale, such as placement height, and the difference in the percentage of combustible and incombustible materials, there is a rough correlation between the placement area for removed contaminants (m^2) and the quantity of removed contaminants (the number of flexible containers) as shown in **Figure 5**. Furthermore, a fixed percentage (0.5–2%) of the area was dedicated to decontamination (**Figure 6**).

(2) Placement of removed contaminants

There were two methods for controlling combustible and incombustible materials in different

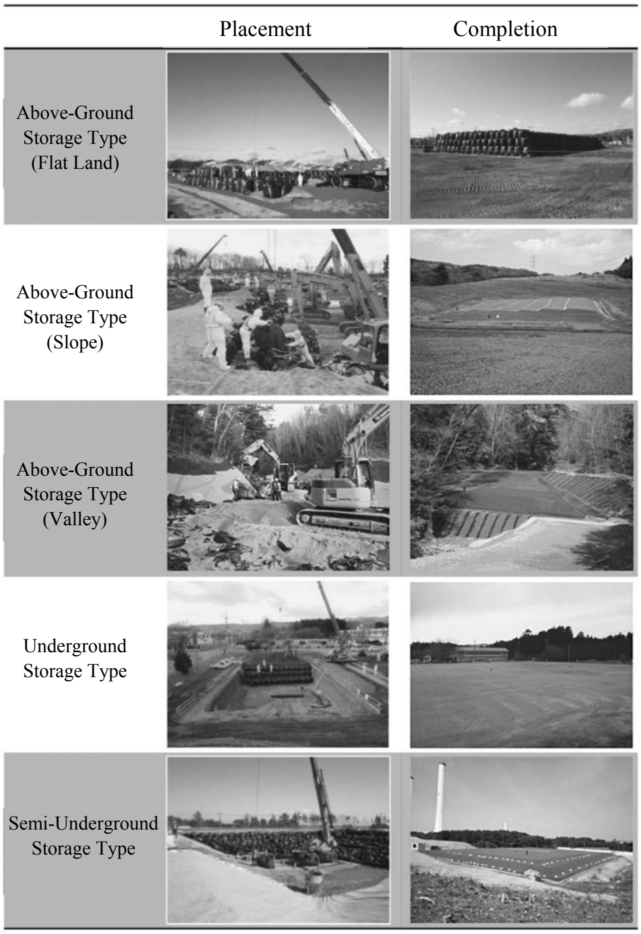


Figure 4 Waste-storage scenarios, and completed temporary storage facilities

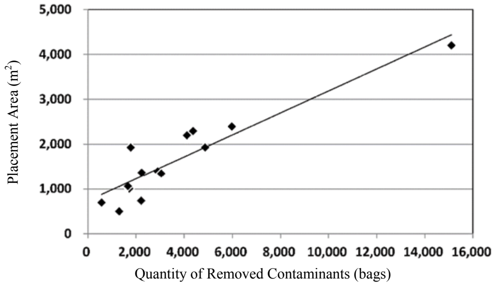


Figure 5 Amount of removed contaminants, and size of temporary storage site

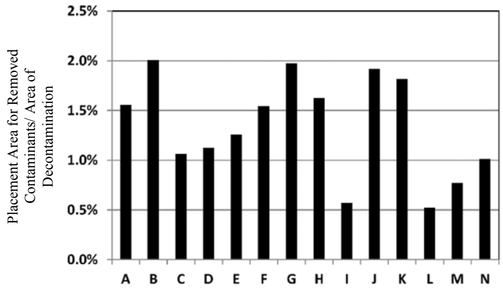


Figure 6 Ratio of area of temporary storage site to area of decontamination target

Table 1 Measures to subsidence of flammable removed contaminants

Storage of Combustible Materials	Type	Actions
Stored separately from incombustible materials	Above-Ground Storage	-Advance volume reduction using a chipper, etc.
		-Limit the number of stacking stages to as few as possible to make the load from upper removed contaminants as low as possible.
Stored in the same section as combustible materials	Above-Ground Storage	-Sandwich of combustible and incombustible materials by making use of the weight of incombustible materials for compression, and by making the residual subsidence as small as possible.
		-To limit the deformation of whole earth filling, only incombustible materials are stacked in the core portion.
		-Place combustible materials on top of the stack of incombustible materials.
	Underground Storage	-Limit the number of stacking stages to as few as possible.
		-Finish the surface by banking up the soil with a slope of several degrees in consideration of later subsidence.

sections and in the same section due to the limited area of the temporary storage yards. When storing combustible materials such as grass and fallen leaves, deformation by subsidence due to the reduced volume and the compression of combustible materials can be expected. Countermeasures for this were implemented as listed in **Table 1**.

The surface dose rate and weight of flexible containers brought into a temporary storage yard were measured in terms of selecting placement positions for the removed contaminants, and controlling the exposure of workers during placement. Specifically, because radiation from the removed contaminants in the inner part of the temporary storage yard is shielded by contaminants located in the outer part, removed contaminants with a higher surface dose rate were placed as close to the center as possible.

Furthermore, traceability during transport to the interim storage facilities, etc., was secured by attaching a tag to each flexible container indicating the surface dose rate of the flexible container, and its weight, collection site, specification of its contents, and its storage location in the temporary storage yard.

4. Monitoring and Maintenance of Temporary Storage Yard

To verify that the soundness of the shielding and radioactivity containment functions in the temporary storage yard is maintained until the removed contaminants are taken out of the interim storage facilities, monitoring was conducted for the following items:

- Air dose rate
- Water levels and radioactivity concentration in leachate and groundwater
- Carbon monoxide concentration and temperature of generated gases
- Deterioration or damage status of equipment in the temporary storage yard

(a) Air dose rate

The air dose rate was measured at several predetermined locations, such as at the site boundary or in temporary storage sections. For underground storage, measurement was conducted above the storage facility, i.e., on the surface of the ground. As a result, it was verified that the air dose rate of the temporary storage yards when completed was less than before bringing the removed contaminants into the storage facility (**Figure 7**). Continuous monitoring was conducted approximately once every week after that. No increase in air dose was observed after approximately three months had passed; the shielding function was maintained.

(b) Water levels and radioactivity concentration in leachate and groundwater

The monitoring interval for leachate was defined based on the relation between water storage capacity and leachate quantity. As a result, the generation of a large amount of water linked to the rise of atmospheric temperature was observed in some of the temporary storage yards. It is thought that the water originated from the frozen peeled surface soil and snow that had fallen into the temporary storage yard during placement. In the temporary storage yard, water quantity and radioactivity concentration were measured once every one or two days, and a dose lower than the concentration limit for water based on the "Notification for Dose Equivalent Limits on the Basis of the Ministerial Ordinance for Installation and Operation of Commercial Power Reactors Mar. 21, FY2001, Ministry of Economy, Trade and Industry (METI) Notification No. 187)" (hereinafter referred to as "concentration limit") was confirmed in the area other than the peripheral monitoring area. Thus the water could be safely discharged. Conversely, the radioactivity level of leachate in some of the facilities exceeded the concentration limit. This

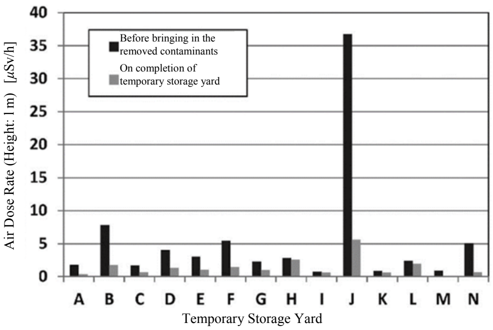


Figure 7 Air dose rates before and after construction of temporary storage facilities

was observed only in sections where combustible materials were stored without a protective soil layer to function as an adsorbent for the dissolved radioactive cesium in the leachate. Furthermore, the flocculent settling process was used on the leachate and discharged after verifying that the concentration level was lower than the specified limit.

The groundwater monitoring interval was set to once every month in accordance with the decontamination guidelines. All the measurements for radioactivity concentration in groundwater were lower than the concentration limit.

(c) Carbon monoxide concentration and temperature of generated gases

The carbon monoxide concentration, and the temperature of generated gases were measured at an interval of approximately once a week, similar to the measurement of the air dose rate, to determine the fluctuation trend. A gas vent pipe was used to measure the carbon monoxide concentration, and the temperature was measured at a depth of approximately 1 m. Furthermore, temperature monitoring with thermal sensors and an underground wireless compact transmitter was tried in some of the temporary storage yards.

As a result, some temporary storage yards showed an increase in temperature up to approximately 55°C in sections where combustible materials were stored, due to the fermentation decomposition of vegetation (**Figure 8**). As the rise in temperature continued, it was necessary to increase the number of gas vent pipes to accelerate the heat dispersion, but this countermeasure was not implemented because the temperature stopped rising and then began to fall. In addition, the generation of carbon monoxide exceeding a concentration of 100 ppm [4], in such environment a fire might happen, did not occur.

(d) Deterioration and damage status of equipment in temporary storage yards

Visual inspection was conducted for the purpose of verifying deterioration and damage in shielding materials, collection pits, gas vent pipes, etc., in the temporary yards. In the extremely

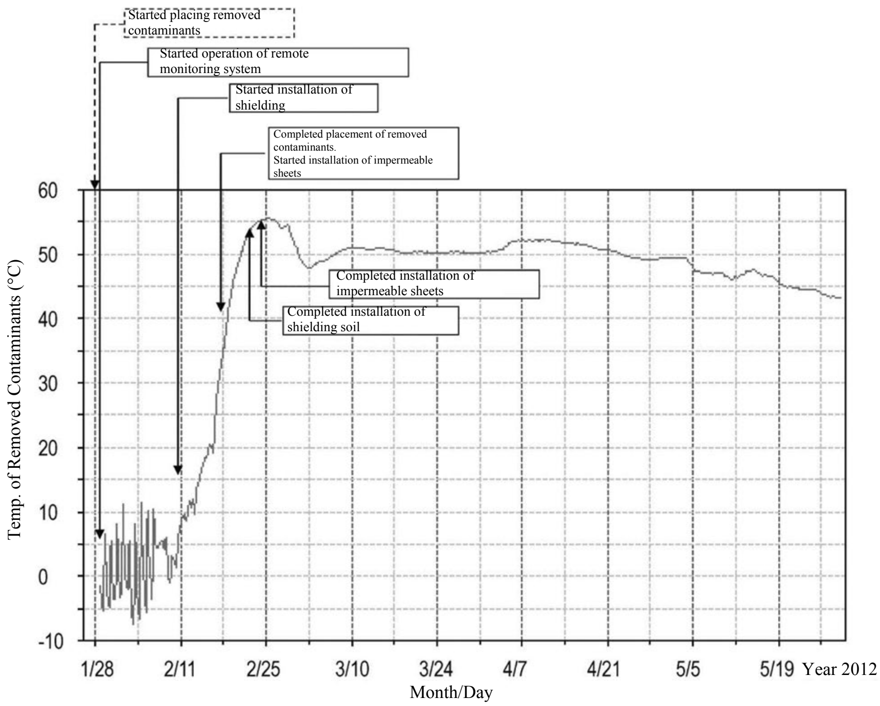


Figure 8 Monitored temperature inside the yard for flammable removed contaminants

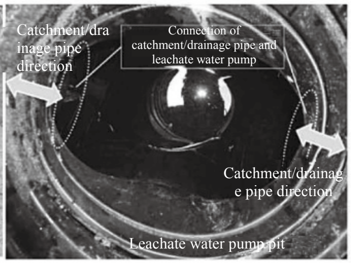
cold area of the Abukuma highlands, the removed contaminants and shielding soils were frozen when the flexible containers were filled. Because of this, as the temperature rose, the flexible containers became deformed due to the melting of the shielding soil, and the flexible containers that were installed outside of the impermeable sheets on the sides shifted or partially collapsed, as shown in **Figure 9(1)**. Furthermore, in this temporary storage yard, the air dose rate did not increase because the sandbags for shielding were placed on the inner side of the flexible containers as well. In some of the temporary storage yards, subsidence occurred in the flexible containers

(1) Shifted and collapsed shielding around flexible containers

(2) Water pooling due to subsidence

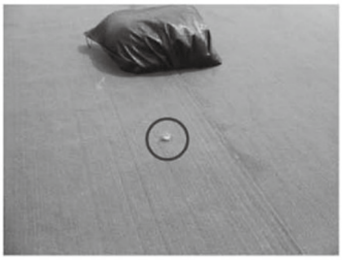
(3) Defective portion around gas vent pipe (after the peeling of cover soil)

Deformation of leachate bilge pump pit due to the weight of flexible containers



Clogged connection with collection/drainage pipe due to the deformation of leachate bilge pump pit

(4) Deformation of Leachate Water Pump Pit



(5) Damage to Protection Mat by Wild Birds (circled)

Figure 9 Problems that occurred at temporary storage facilities due to the humification of combustible materials and the melting of frozen soils (**Figure 9(2)**).

In some of the temporary storage yards in which uneven subsidence occurred, there was defective welding between the gas vent pipe and the impermeable sheet (**Figure 9(3)**), and infiltration of rainwater through the defective area occurred during heavy rainfall. Defective welding was found on part of the upper impermeable sheet, and there was evidence of the infiltration of rainwater in some yards.

The low workability may have promoted the occurrence of defects because the impermeable sheet had to be welded on an uneven surface above a group of flexible containers, instead of on a flat one.

In addition, there was a problem with water drainage due to the deformation of the leachate bilge pump pit to drain the leachate stored in the dam (**Figure 9(4)**). The cause was considered to be that the leachate bilge pump pit was located near a slope, so horizontal stress was generated by the weight of the removed contaminants, and at the same time, the flexible container and the leachate bilge pump pit prevented the dispersion of the weight of the removed contaminants in the leachate bilge pump pit.

Partial damage to the protective mat in the upper part of contaminants occurred as well, which was attributed to a wild bird (**Figure 9(5)**). Furthermore, some signs of intrusion by wild pigs and feral cows on the premises of some of the temporary storage yards were observed, but until now, no specific problem has been observed.

IV. Technical Know-How

The technical know-how that is considered applicable to future temporary storage yards is identified and summarized.

1. Design and Construction of Temporary Storage Yards

(1) Types of temporary storage yards

The advantages and disadvantages of temporary storage yard types are summarized in **Table 2**. Considering their advantages and disadvantages, the types of temporary storage yards were selected according to the procedure indicated in **Figure 10**. In Table 2, “Easy construction according to topographical conditions” is an advantage for above-ground storage, but the following points must be considered if the location is a slope or a valley:

- For sloped land, earth retaining walls and dams must be installed in lower areas according to the gradient. Furthermore, land preparation with cutting or filling may be necessary.
- Where the slope is utilized as a direct loading area for the removed contaminants, such as in a valley, radiation shielding measures in the slope zone are not required. However, providing a means to securely guide the slope surface water downstream are needed, as are measures to lower the groundwater level because the water pressure from the back end tends to put pressure on the impermeable sheets.

(2) Specifications for facility requirements

The advantages and disadvantages of various specifications are listed in **Tables 3–5**, such as the shielding and placement methods for the removed contaminants, which differ depending on the temporary storage yard. It is necessary to optimize the specifications while considering these advantages and disadvantages when maintaining temporary storage yards during

Table 2 Advantages and disadvantages of temporary storage yard types

Type	Advantage	Disadvantage
Above-Ground Storage	- Easy removal for transport to interim storage facilities, etc. - Easy to transport the removed contaminants after placement (ease of inspection/repair). - Easy installation according to topographical conditions.	- The shielding soil must be secured from other regions. - Construction on a soft footing requires improvement of soil.
Underground Storage	- Shielding soil is secured at the site (low activity concentration in dug out soil, excluding surface soil). - Construction is possible without improvement to soil footing, even in locations with soft footing. - Easy repair/inspection of covering soil. - Maintained landscapes.	- Requires time for digging and building the underground zone. - When the removed contaminants are placed lower than groundwater level, groundwater infiltration prevention and groundwater drawdown measures are required. - Digging operations are required for transporting removed contaminants.
Semi-Underground Storage	- It is possible to increase the placement quantity in a small area with a comparatively greater number of stages compared to stacking in above-ground and underground zones. - Easier shielding by placing the higher-concentration removed contaminants in an underground zone, and placing removed contaminants with comparatively lower concentration in the above-ground zone. - Shielding soil is secured at the site (low activity concentration in dug-out soil, excluding surface soil).	- Requires time for digging and building the underground zone. - Rainwater infiltration prevention measure is required at the boundary of the above-ground and underground zones. - When the removed contaminants are to be placed lower than the groundwater level, groundwater infiltration prevention and groundwater suppression measures are required.

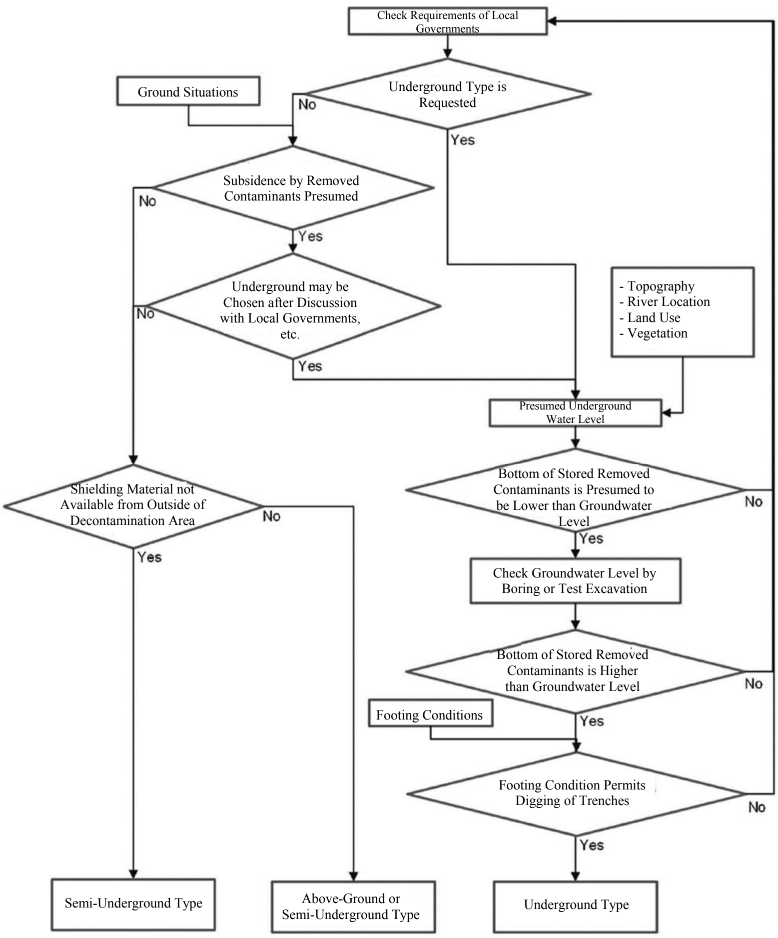


Figure 10 Flowchart for type selection of temporary storage facilities

Table 3 Advantages and disadvantages of shielding methods for upper faces

Position and Method of Placement of Shielding Materials	Advantage	Disadvantage
Inside of Impermeable Sheet		
Earth Fill	- The necessary quantity of soil can be used to provide a shielding function - Easily adapts to variations in volume	- Damage to sheets by ultraviolet rays, birds, and animals must be anticipated and avoided (Damage is prevented by covering with a protective light-shielding mat). - Large-scale installation work - Checking for earth fill contamination is required when contaminants are taken out, and if contaminated, the interim storage quantity increases.
Flexible Container	- Easy installation and removal ✓ Easy installation on a slope ✓ Easy to locate defects in the impermeable sheet, and easy to repair.	- Damage to sheets by ultraviolet rays, birds, and animals must be anticipated and avoided (Damage is prevented by covering with a protective light-shielding mat). - Excessive quantity may be used for shield. - Checking of shielding soil contamination is required during removal because the flexible containers come into contact with removed contaminants, and if contaminated, the interim storage quantity increases.
Outside of Impermeable Sheet		
Earth Fill	- The necessary quantity of soil can be used as a shield - Easy installation work	- The impermeable sheets become stressed when subsidence occurs due to the reduction in volume of the removed contaminants. - For any repair, careful operation is required to remove the earth fill without damaging the impermeable sheets.
Flexible Container	- Damage to sheets by ultraviolet rays, birds, and animals is prevented.	- The impermeable sheets are stressed when subsidence occurs due to the volume reduction of removed contaminants.

Table 4 Advantages and disadvantages of shielding methods for lateral faces

Position and Method of Placement of Shielding Materials	Advantage	Disadvantage
Inside of Impermeable Sheet		
Earth Fill	- The necessary quantity of soil can be used as a shield - Easily adapts to variations in volume	- Damage to sheets by ultraviolet rays, birds, and animals must be anticipated and avoided. (Damage is prevented by covering with a protective light-shielding mat.) - Large-scale installation work - Check of earth fill contamination is required during removal, and if contaminated, the interim storage quantity increases. - For any kind of repair, construction work will be difficult. - Temporary storage yard area is increased due to the requirements of certain degrees of slope to secure stability.
Flexible Container	- Easy installation and removal ✓ Easy installation ✓ Easy to find a defect in the impermeable sheet, easy to repair. - A steeper slope than for earth filling provides rationalization for the temporary storage yard area.	- Damage to sheets by ultraviolet rays, birds, and animals must be anticipated and avoided. (Damage is prevented by covering with a protective light-shielding mat.) - Excess may be used for shielding. - Checking of shielding soil contamination is required during removal because the flexible containers come into contact with the removed contaminants, and if contaminated, the interim storage quantity increases.
Outside of Impermeable Sheet		
Earth Fill	—	—
Flexible Container	- Damage to sheets by ultraviolet rays, birds, and animals is prevented.	- Possibility of shifting due to deformation caused by the melting of frozen shielding soil in extremely cold areas.

Table 5 Advantages and disadvantages of each technical specification (except shielding method)

Specification		Advantage	Disadvantage
Placement of combustible and incombustible material	Separated into Sections	- Easy sorting during removal for transport to interim storage facilities.	- A large temporary storage yard area is required due to the limitation in area/height of temporary storage yards for prevention of combustible material fires
	Same Area	- Minimized roughness on the sheet surfaces due to the subsidence of flexible containers for combustible material by devising the layout of combustible and incombustible materials - Low risk of fire	- Possibility of breakage due to loading on the welded portion of impermeable sheets because of unequal subsidence rates between combustible and incombustible materials
Active use of slopes as direct loading zones	Yes	- Easy adaptation to narrow lots. - Shielding not required.	- Water pressure tends to put pressure on the impermeable sheets when the backend groundwater level is high (a countermeasure for groundwater, such as the application of waterproof treatment on slopes, etc., depending on the situation).
	No	- No influence due to the pressure of groundwater from the slopes.	- A larger cleared area is required in mountainous areas.
Storage of Leachate Water	Catchment Pit	- Easy monitoring of leached quantity from the temporary storage yard, and the outflow of cesium.	- Determining catchment pit volume is difficult
	Dam	- Storage of large volumes of leachate water.	- Larger installation area
Presence of Protective Soil	Yes	- Function as a cesium-adsorbing layer is expected when the leakage of cesium occurs accidentally. - Possible to protect of impermeable sheet at bottom	- Increased volume of temporary storage yard - Possibility of protective soil contamination by cesium
	No	- The volume of the temporary storage yard does not increase. - Securing non-contaminated soil is not necessary. - No possibility of increased interim storage quantity due to the contamination of protected soil.	- Separate action is required if the accidental leakage of cesium occurs. - There is a risk of damage to the water impermeable sheets from protruding objects such as branches and leaves. - It is not possible for heavy machinery to enter the section.
Subsidence Prevention Measure	Yes	- No stagnation etc. of rainwater on top because there is no subsidence.	- A pre-treatment facility or place is required. - There may be barriers to the decontamination operation because the contaminated materials are not promptly brought into the temporary storage yard.
	No	- Easy installation of temporary storage yards. - Pre-treatment is not required.	- Rainwater, etc., may stagnate due to subsidence, and the stagnated water may flow into the temporary storage yard.

full-scale decontamination, etc., to be conducted in the future.

(3) Construction of temporary storage yards

The estimation of the quantity of removed contaminants and the real data may be significantly different due to the various decontamination methods, etc. used during the decontamination operation. Because of this concern, it is safer to carry out step-wise construction in accordance with the status of the generation of removed contaminants during the decontamination operation by setting up multiple sections, instead of constructing all the storage areas for the removed contaminants at once. As preventive measures for volume reduction or compression of combustible materials, and subsidence due to the melting of frozen soils, it is possible to fill the gaps between flexible containers with filling sand, etc.

(4) Maintenance and management of temporary storage yards

(a) Air dose rate

- The air dose rate is an indicator for locating defects, and for the early detection of defects in shielding by measuring between sections as well when there are multiple temporary storage yards in addition to land boundaries.

- It is desirable to monitor the upper part of covering soils because verification of shielding performance on the upper surface is important for underground temporary storage yards.

(b) Radioactivity concentration in groundwater

- The installation of observation wells for groundwater on upstream and downstream sides of the temporary storage yard facilitate the verification of radioactive material leaching from the temporary storage yard when radioactive material is detected in the groundwater.

- The direction of overall groundwater flow is estimated from the topography and location of rivers, etc.

- When an abnormality is recognized in radioactivity concentration in groundwater, action is required to prevent the spread of groundwater contamination after identifying the cause. Specific actions include the inspection and repair of impermeable sheets, pumping contaminated groundwater, etc. Furthermore, where there are domestic wells in the vicinity, it is necessary to conduct a prompt analysis of the relevant wells and to implement water restriction.

(c) Radioactivity concentration in leachate

- It is expected that radioactive cesium may be adsorbed by the protective soil before leachate containing dissolved radioactive cesium flows into the collection pit.

- When the radioactivity concentration of the leachate in the collection pit is higher than the concentration limit, a treatment to remove the radioactive cesium must be implemented. To do this, materials capable of cesium adsorption, such as zeolite, etc., are used for ionized cesium. Conversely, filtering or flocculent settling is considered appropriate for muddy water that contains soil with adhered radioactive cesium.

- Increased radioactivity concentration is possible in the collection pit due to the mixture of water and removed contaminants from water infiltration caused by degradation of the impermeability of the upper impermeable sheets. Considering the increased leachate water quantity in this case, the monitoring of leachate water flow is summarized in **Figure 11**.

(d) Deterioration and damage status of temporary storage yards

- Normally, visual inspection is conducted for deterioration and damage to shielding materials and impermeable sheets, collection pit, and gas vent pipes in the temporary storage yard, but the following phenomena enable inference due to deterioration or damage of impermeable sheets for which full visual inspection is difficult:

✓ When the upper impermeable sheets are damaged, an increase in the water quantity due to precipitation in the collection pit is observed.

✓ The water quantity flowing into the collection pit decreases due to the degraded shielding performance of the impermeable sheets at the bottom.

- To identify and repair the damaged parts of impermeable sheets in the upper part, visual inspection is mainly conducted when the impermeable sheets are exposed, and when they are covered with flexible containers, these are moved as necessary before inspection.

- If damage to the impermeable sheets in the bottom part is in question, the damaged part must be located by moving the removed contaminants.

(e) Automatic monitoring system

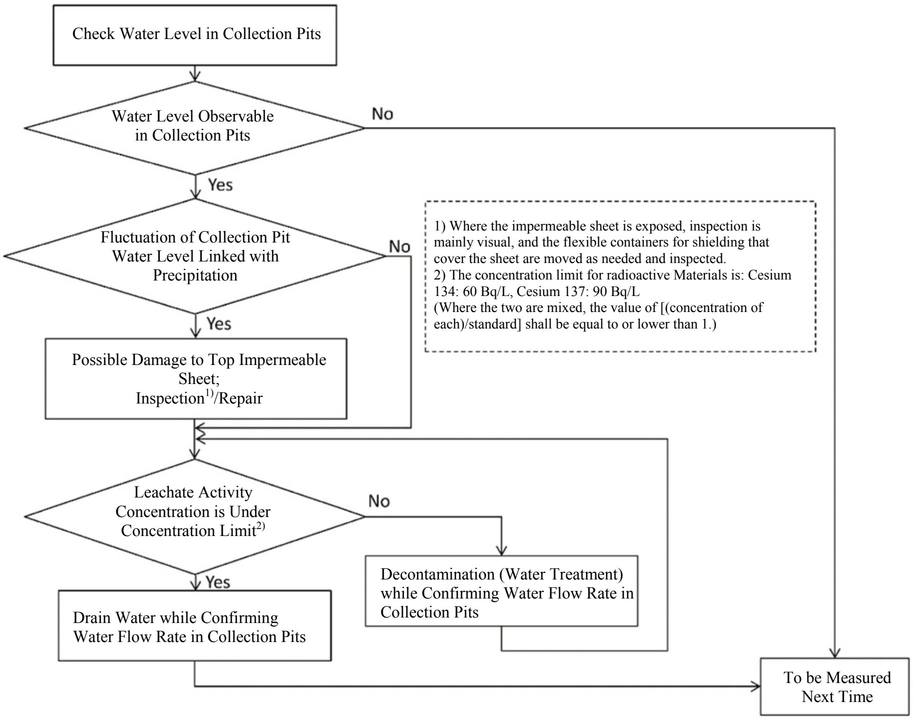


Figure 11 Flowchart of monitoring of seepage water

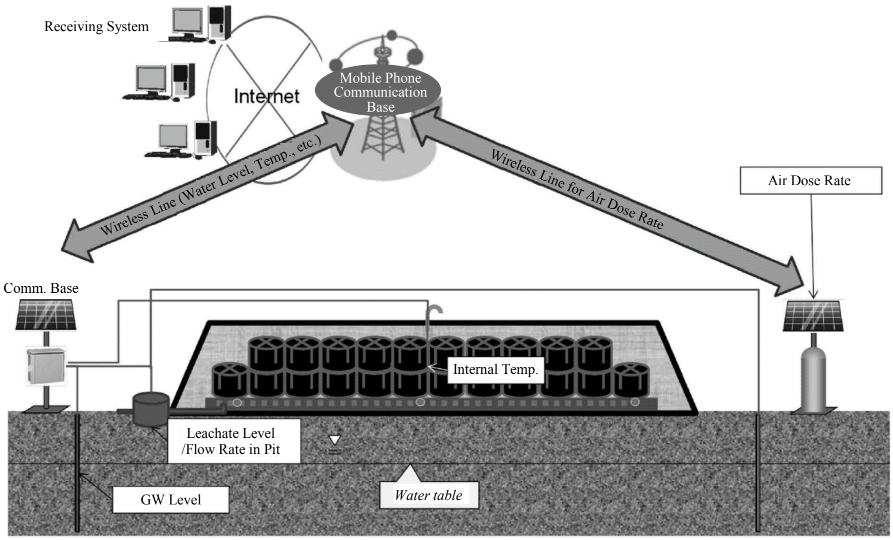


Figure 12 Concept of automatic monitoring system

An automatic monitoring system was implemented to facilitate the remote monitoring of the air dose rate and the temperature in some temporary storage yards during the decontamination pilot projects. Remote monitoring of the fluctuation in air dose, leachate quantity, groundwater level, temperature, etc. via an automatic monitoring system using wireless communications, such as mobile phones, as shown in **Figure 12**, is considered advantageous in terms of the following points:

- Live monitoring of the soundness of radioactive shielding, and containment of radioactive materials.
- Prompt action in the event of an abnormality
- Reduced labor for monitoring personnel and reduced time in high dose areas, such as a caution zone, and in mountainous areas.
- Timely publication of monitored results.

V. Summary

With this paper, we aim to contribute to the maintenance of temporary storage yards constructed in the future. Technical know-how was extracted and organized based on actual experience.

Based on actual experience with the design construction, maintenance, and management of multiple temporary storage yards having different specifications, technical know-how regarding the site selection, type, and specifications of facility requirements were extracted and organized. For the maintenance of temporary storage yards during full-scale decontamination in the future, it is considered beneficial to actively apply this technical know-how, and focus on the justification for specifications according to the conditions at the installation site.

In the future, it will be necessary to continue monitoring to verify the soundness of radioactivity shielding and the containment of radioactive materials in the temporary storage yards. Whenever an abnormality is detected, the appropriate action will need to be taken. It is considered beneficial to extract and organize the technical know-how acquired by those responsible, as this paper does, and to share this among the many temporary storage yards to be constructed in the future to maintain highly safe, stable, and evidence-based storage facilities, and to promote the understanding of local residents.

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This research adds to the achievements already made by the commissioned Government project “Decontamination Demonstration Projects on Evacuation Areas, etc., for the Fukushima Daiichi Nuclear Power Plant Accident.”

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