3. Management and treatment of decontamination wastes

3.1. Temporary Storage Sites and Final Disposal

3.1.1. Waste Treatment Flow and Necessity of Temporary Storage Sites

As shown in Chapter 1, the "Urgent Implementation Basic Policy on Decontamination" ("Urgent Implimentation Policy" in this document) (announced on August 26, 2011 by the Nuclear Emergency Response Headquarters (NERH); hereafter referred to as the "Basic Policy on Decontamination") prescribes that, concerning the following description about the disposal of wastes and soil contaminated by radioactive materials: "The National Government shall be responsible for securing disposal sites that require long-term management as well as safety of such sites, and will create and announce a roadmap to construct such sites as quickly as possible."

On the other hand, the Basic Policy on Decontamination also states: "Time is needed to secure and prepare disposal sites that require long-term management. Decontamination might not proceed quickly if such disposal sites must be put in place first." The Basic Policy on Decontamination stresses the needs of temporary storage sites as: "It is realistic that such temporary storage site(s) is (are) to be located ineach municipality or community has its own individual temporary storage site(s) for the time being to keep soil and wastes produced by decontamination."

In response the MOE on October 29, 2011,presented its basic philosophy "Basic Philosophy on Interim Storage and Other Facilities Required for the Handling of the Environmental Pollution from Radioactive Materials Associated with the Accident at the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company" (hereafter referred to as the "MOE Basic Philosophy on Interim Storage"),

The MOE Basic Philosophy on Interim Storage is summarized in Figures 3-1 to 3-3, and includes the flow schematics for treatment of wastes and the roadmap towards the installation of an interim storage facility in Fukushima Prefecture, where significant amounts of removed soil and other wastes are anticipated to be produced.

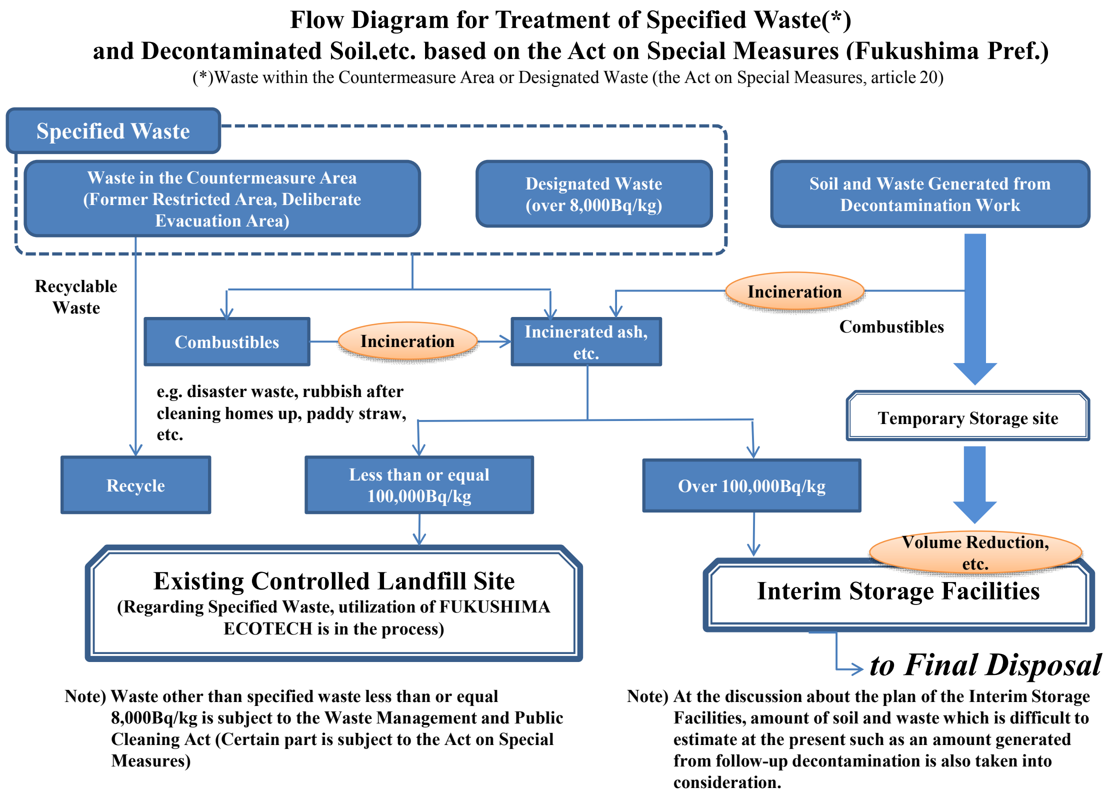


Figure 3-1 Treatment flow of specified and other wastes produced in decontamination (Fukushima Prefecture)[80].

[80]Source: Ministry of the Environment (MOE), "Basic Philosophy on Interim Storage and Other Facilities

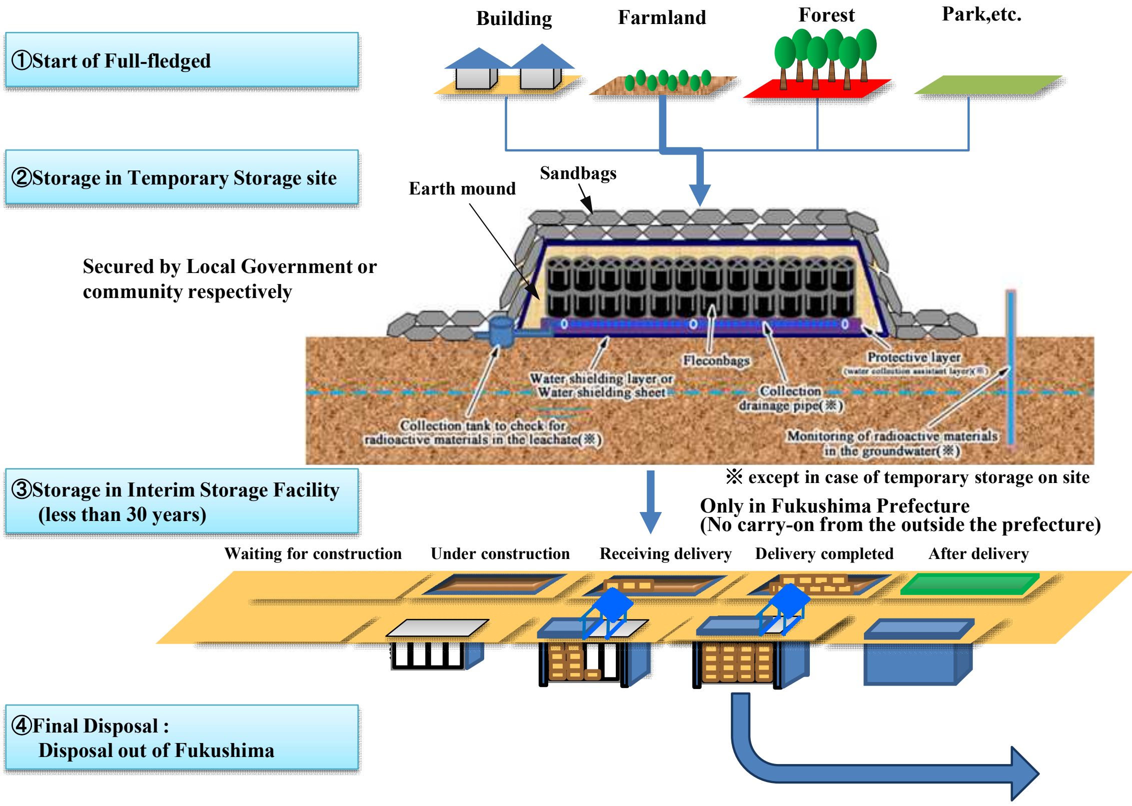


Figure 3-2 Treatment of soil and wastes produced in decontamination (Fukushima Prefecture).

Required for the Handling of the Environmental Pollution from Radioactive Materials Associated with the Accident at the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company" (October 29, 2011). Figure 3-3 and Figure 3-3 are generated from the same source.

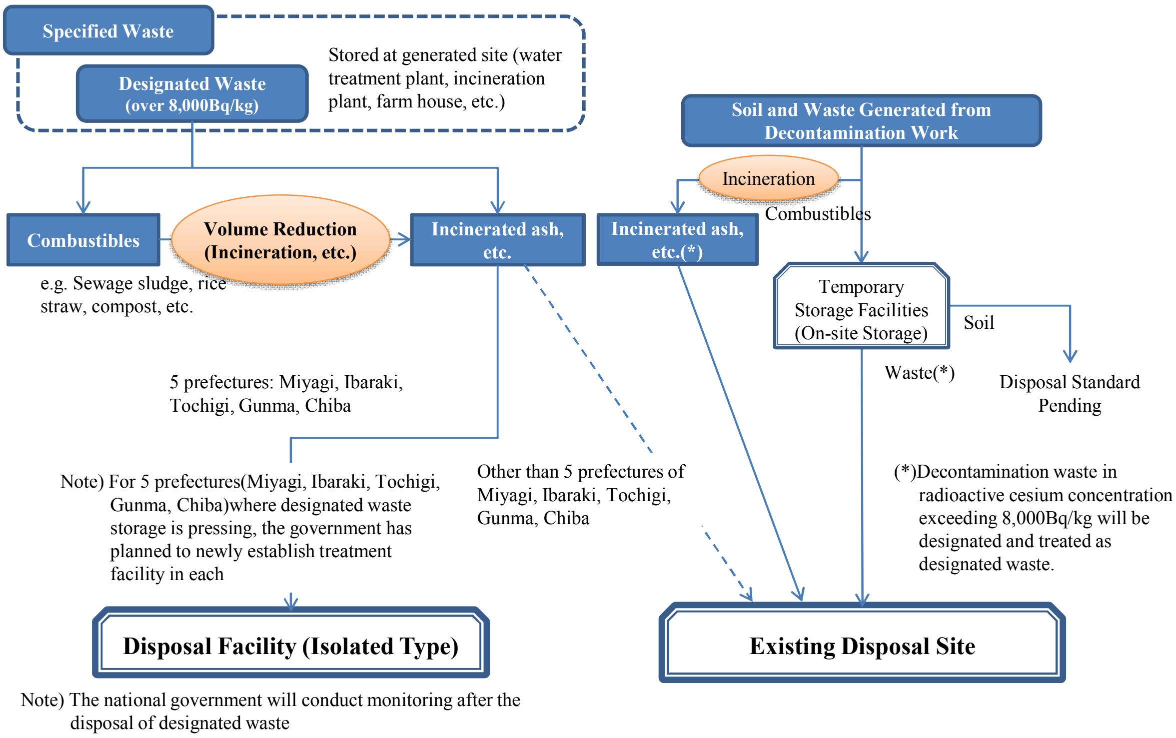


Figure 3-3 Treatment flow of specified and other wastes produced in decontamination (areas outside Fukushima Prefecture).

3.1.2. Configurations of Temporary Storage Sites

Facility configurations, their management, and other conditions necessary for temporary storage sites to quickly begin decontamination work are specified in the “Guidelines Pertaining to the Storage of Removed Soil” as shown in Chapter 2.4 of this Decontamination Report (the “report” in this document).

However, most of the descriptions in the Guidelines are relevant to the prevention of effects from radioactive materials on human health and the living environment. In the installation of a temporary site, there are other conditions required, too, such as fire prevention measures.

Basic configurations of temporary storage sites are shown below in more detail, using the classifications for the wastes to be stored in the temporary storage sites.

(1) Storage of combustibles

Combustibles such as naturally fallen leaves and branches, and intentionally cut branches, etc. generate gases by their decomposition and when accumulated, that might lead to a fire. Therefore, they should be covered with gas- and air-permeable waterproof sheets or the like and gas venting pipes should be provided. Storage conditions of wastes should be checked regularly, and if white smoke or steam, etc. is noticed, appropriate management measures should be taken by, for instance, measuring the interior temperatures of the accumulated wastes (Figure 3-4).

(2) Storage of non-combustibles like soil

Non-combustibles like removed soil may be stored after being covered with waterproof (seepage control) sheets, since they do not generate gases during storage (Figure 3-5).

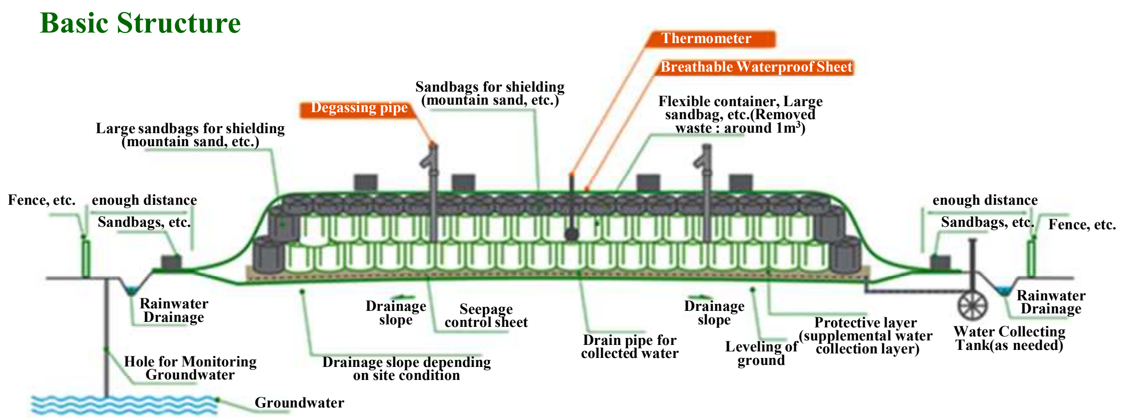


Figure 3-4 Basic configuration of a temporary storage site above ground for combustibles removed in decontamination work[81].

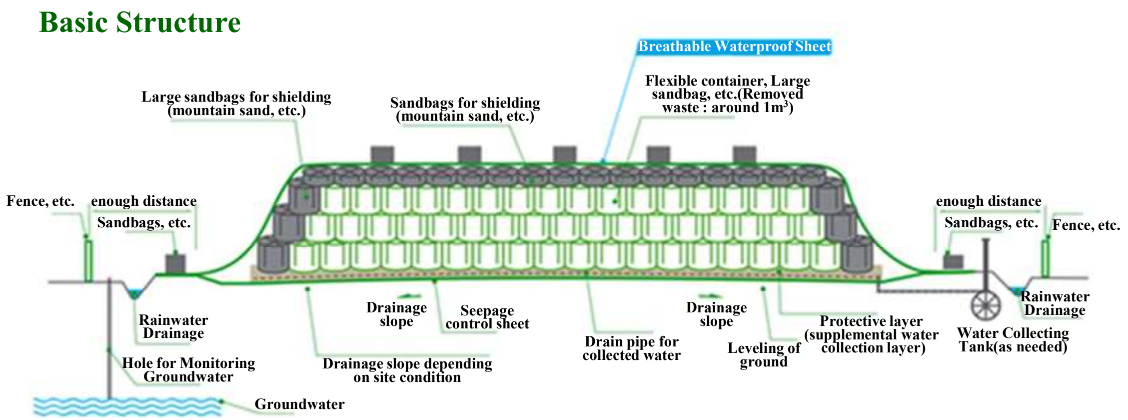


Figure 3-5 Basic configuration of a temporary storage site above ground for non-combustibles removed in decontamination work.

[81]Source: Decontamination Information Site (http://josen.env.go.jp/soil/temporary_place.html). Figure 3-5 has the same source.

3.1.3. Examples of Temporary Storage Sites

Some examples of temporary storage sites cited from the "Temporary Storage Site Installation Casebook" (August, 2013), which was compiled by the Division of Fukushima Prefecture Decontamination Measures, are presented here.

As given in Table 3-1, the above-mentioned document gives ten examples of temporary storage sites, two examples of air dose rate measurements, and an example of a field observation tour to a temporary storage site.

Figures 3-6 to 3-10 show examples of temporary storage sites located in a swimming pool, a forest, an abandoned quarry, the vicinity of a condominium, and a dry field.

Table 3-1 Examples collected in the "Temporary Storage Sites Casebook"[82]

Content	Example
Examples of installation	i) Public facility (Pool) (Koori town) ii) Paddy field (Yugawa village) iii) Plowed field (Kawamata town, Ten-ei village) iv) Forest (Miharu town, Tamakawa village) v) Residents area neighborhood (Koori town, Date city) vi) Land adjacent to paddy field and orchard (Date city) vii) Utilization of mountain sand collection place ruins (Date city)
Measurement of air dose rate	i) Housing development neighborhood (Koori town) ii) Plowed field (Kawamata town)
Field inspection party of temporary storage site	Field inspection party of temporary storage site for Ono town inhabitants (Kawamata town)

[82] Source: Division of Fukushima Prefecture Decontamination Measures, "Temporary Storage Site Installation Examples" (August, 2013). (Figure 3-6 to Figure 3-10 are generated from the same source.)

(1)　A temporary storage site using a swimming pool

【 Before installation 】

【 After installation 】

Area, etc.	Approx. 2,500m^2 (municipal ownership place)
Waste to be delivered	Removed soil and vegetation generated by decontamination of educational facilities
Form of facility Storage Capacity	Semi-underground facility Approx. 1,100m^3 (using weather resistance large sandbags)
Status of management	○Air dose rate (measuring daily (week day)) [before delivery] 0.47μSv/h(2012.5) [after delivery] 0.28μSv/h(2013.7) ○Radioactivity concentration of the groundwater (measuring weekly) [Before delivery] N.D.(2012.5) [After delivery] N.D.(2013.7) ○Radioactivity concentration of the leachate (measuring when the leachate is discovered)
Location of installation	The facility has been installed with the public pool which was not used in an earthquake disaster. It is approx. 30 meters to the most recent residential house.

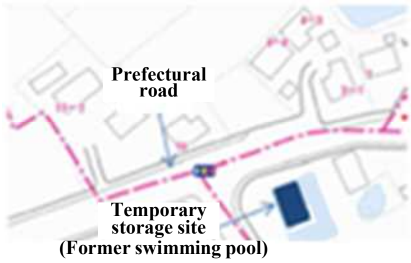


Figure3-6 A temporary storage site using a swimming pool.

(2)　A temporary storage site in a forest

【 Before installation 】

【 After installation 】

Area, etc.	4,683m^2 (national forest)
Wastes to be delivered	Removed soil and fallen leaves generated by decontamination of school and school route, etc.
Form of Facility Storage Capacity	Above ground facility Approx. 1,788m^3 (using flexible container)
Status of management	○Air dose rate (measuring weekly) [Before delivery] 0.26μSv/h(2012.11) [After delivery] 0.14μSv/h(2013.5) ○Radioactivity concentration of the groundwater (measuring monthly) [Before delivery] N.D.(2013.5) [After delivery] N.D.(2013.6) ○Radioactivity concentration of the leachate (measuring when the leachate is discovered)
Location of installation	The national forest has been developed for the installation of temporary storage site. A swamp flows near. (approx. 10 meters to the swamp) It is approximately 500 meters to the most recent residential house.

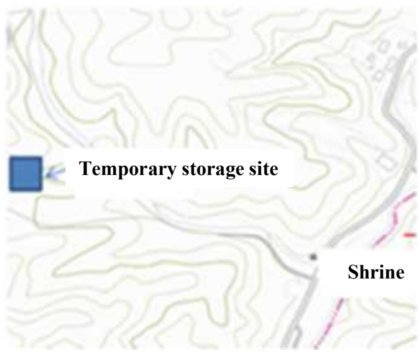
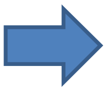


Figure 3-7 A temporary storage site in a forest.

(3) A temporary storage site in an abandoned place digging out sand in a mountain

【 Before installation 】



【 After installation 】

Area, etc.	9,894m² (private land)
Wastes to be delivered	Removed soil and vegetation generated by decontamination of residential houses and roads
Form of Facility Storage Capacity	Above ground facility 3,303m³ Breakdown : Combustibles:552m³ Incombustibles:2,751m³(using flexible container)(city ordering)
Status of management	○Air dose rate (measuring weekly) [Before delivery] 0.33μSv/h(2013.1) [After delivery] 0.57μSv/h(2013.8) ○Radioactivity concentration of on-site pond water (measuring monthly) [Before delivery] N.D.(2012.12) [After delivery] N.D.(2013.8) ○Radioactivity concentration of the leachate (measuring when the leachate is discovered)

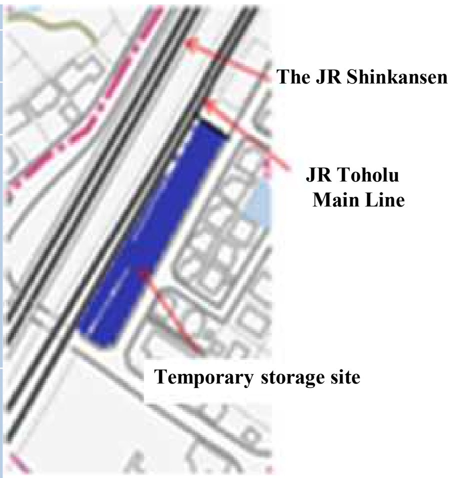
【 Temporary storage site inside 】

Figure 3-8 A temporary storage site in an abandoned place digging out sand in a mountain.

（4） A temporary storage site near a residential area

⑤-1 Residents Area Neighborhood (Koori town)

Area, etc.	Approx. 900m^2 (Municipal ownership place)
Wastes to be delivered	Removed soil and vegetation generated by decontamination of residential house
Form of Facility	Semi-underground facility
Storage Capacity	750m^3 (using flexible container)
Status of management	○Air dose rate (measuring daily (week day)) [Before delivery] 0.62μSv/h(2012.11) [After delivery] 0.26μSv/h(2013.6) ○Radioactivity concentration of the groundwater (measuring monthly) [Before delivery] N.D.(2012.11) [After delivery] N.D.(2013.6) ○Radioactivity concentration of the leachate (measuring when the leachate is discovered)
Location of installation	The temporary storage site has been installed using Green belt between residential area and railway(Tohoku Main Line) . It is approximately 10 meters to the most recent residential house.



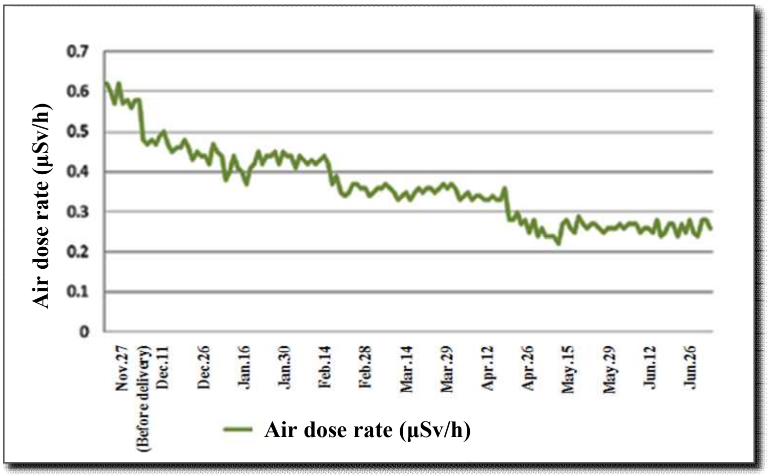


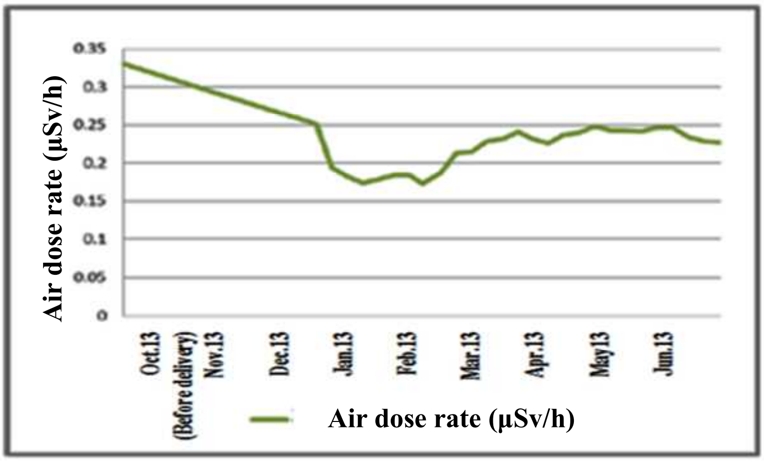
Figure 3-9 A temporary storage site in the vicinity of a condominium.

(5) A temporary storage site in a dry field

[Before installation]

[After installation]

Area, etc.	20,331m² (private land)
Wastes to be delivered	Removed soil,etc. generated by decontamination of residential house and road,etc.
Form of Facility Storage Capacity	Above ground facility Approx. 5,350m³ (using weather resistance large sandbags)
Status of management	○Air dose rate (measuring weekly) [Before delivered] 0.33μSv/h(2012.10) [After delivered] 0.25μSv/h(2013.6) ○Radioactivity concentration of the swamp water (measuring monthly) [After delivered] N.D.(2013.6) * Because water level under the ground is low and specimen can not be gathered, the swamp water is measured. ○Radioactivity concentration of the leachate (measuring when the leachate is discovered)
Location of installation	Mulberry field has been developed for the installation of temporary storage site. It is approximately 200 meters to the most recent residential house.



* Measuring air dose rate at the plural points in the temporary storage site
* Reason why the air dose rate decreased during January to March is considered to be the effect of shielding by snow.

Figure 3-10　A temporary storage site in a dry field.

3.2. Wastewater Treatment

3.2.1. Notes of Caution for Wastewater Treatment

Water is used in high-pressure water cleaning of roofs, roads and the like for decontamination as well as possibly in the cleaning of tools used for decontamination.

Wastewater used in these tasks must be treated appropriately, as it might have been contaminated by radioactive materials. However, most radioactive cesium is in a form that is strongly adsorbed on soil particles, and hardly any of it will dissolve into the wastewater. Therefore, the central element of wastewater treatment is to remove fine soil particles contained in the wastewater.

（1） Necessity of wastewater collection and treatment

The “Guidelines Pertaining to Decontamination and Other Measures,“ mentioned in Chapter 2.2 of this report specifies that no wastewater treatment is essentially needed in cases where soil sediments are removed in the decontamination work in decontamination areas (areas subject to the decontamination plans established by relevant municipalities).

However, in principle, wastewater should be treated in situations where the wastewater is highly turbid or the wastewater has been collected from high-pressure water washing with vacuum collection of water.

（2） Notes of caution for decontamination of water used for washing

When decontaminating using water, the sequence of decontamination should be determined as shown below with consideration of water transfer (Chapter 2.2). The wastewater discharge channels should be checked, the wastewater flow should be dammed up using sandbags and the like as needed to allow fine soil particles contained in it to settle and be collected. Then the supernatant liquid may be discharged (Figure 3-11). Actual scenes and methods of wastewater treatment are shown in Figure 3-12 and Figure 3-13. Figure 3-14 shows an example of high-pressure water cleaning equipment with vacuum collection of water.

In Fukushima City and other municipalities, there have been examples of formulating decontamination plans, as seen in Figure 3-15, in consideration of local rainwater and surface water flows, when planning the decontamination works..

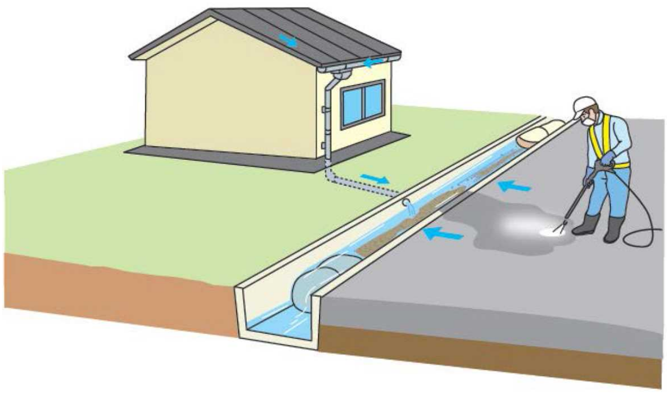


Figure 3-11 Treatment of wastewater used in washing (including sedimentation already present in the street drains)[83].

[83]Source: Ministry of the Environment (MOE) “Guidelines pertaining to decontamination and other measures“ (2nd Edition (amended in December 2014)), http://josen.env.go.jp/material/pdf/josen-gl02_ver2_supplement1412.pdf),

Figure 3-12　Treatment of wastewater used in washing (Kawauchi Village)[84]

8. Treatment of wastewater from cleaning

Cleaning is essential in the house decontamination, but it is difficult to recover all the wastewater. The measures such as follows are taken on the site.

①Minimizing use of water with water for the last finish, in advance removing moss, soil, and the like with radioactive materials by hand which deposit on roof, rainwater guttering, etc., then absolutely decreasing migration of radioactive materials into cleaning water.

(The past 19 times measurement results of wastewater from cleaning: approx. 36Bq/l on average)

②Reducing a outflow of radioactive materials to lower basin by installing "filtering device" using zeolite in street drains to which wastewater is channeled. However, this method requires the establishment of storage area like temporary storage site, etc. for sedimented soil and spent zeolite.

(The past 19 times measurement results of wastewater from cleaning: approx. 10Bq/l on average after filtration, resulting in average reduction rate of 73%)

<Example of "Filtering Device" using street drains>

・Because radioactive cesium is almost adhered to soil, "Filtering Device" as shown in the rough sketch below shall be installed so that muddy water in wastewater does not flow out to lower basin, sedimented soil.

・Very small amount of radioactive cesium contained in supernatant liquid shall be adsorbed to zeolite, etc.

Example of construction

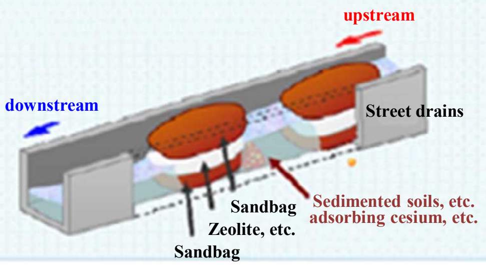


Figure 3-13　Treatment of wastewater used in washing (Fukushima Prefecture)[85].

[84]Source: Kawauchi Village (October 1, 2013), Decontamination and dose control for villagers to return from full evacuation

[85]Source: Fukushima City (January 2013), Decontamination status in Fukushima City, Fukushima City (January 2013)

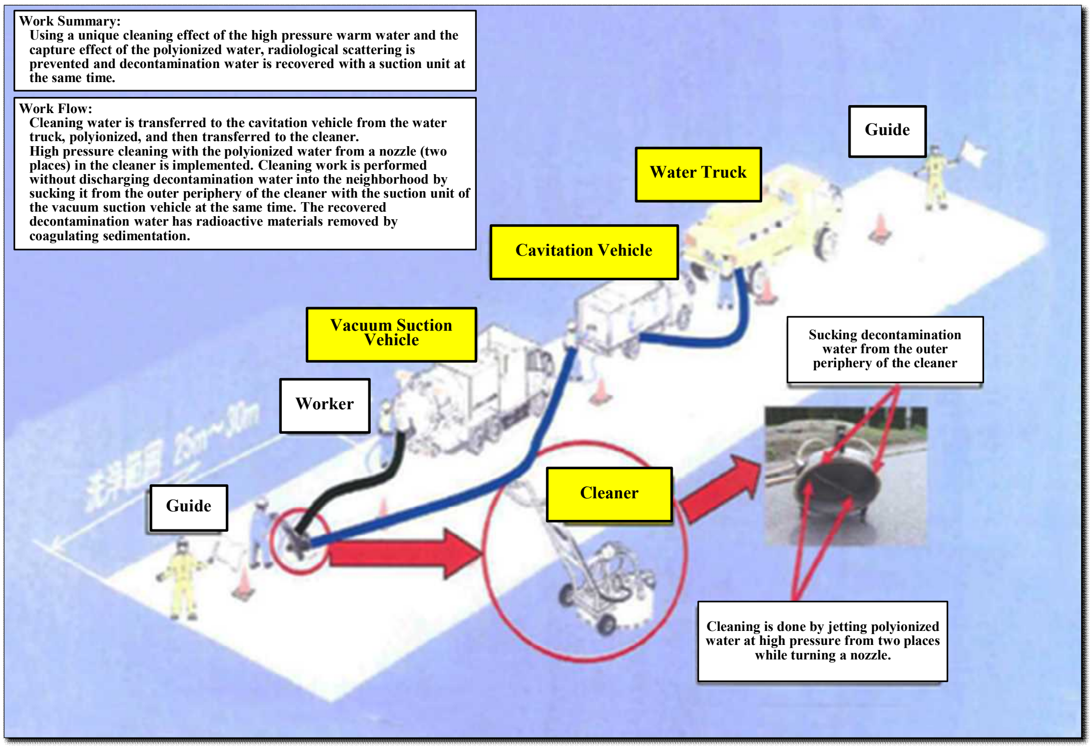


Figure 3-14 Decontamination of roads by high-pressure washing with vacuum collection of the water used (Kawauchi Village)[86].

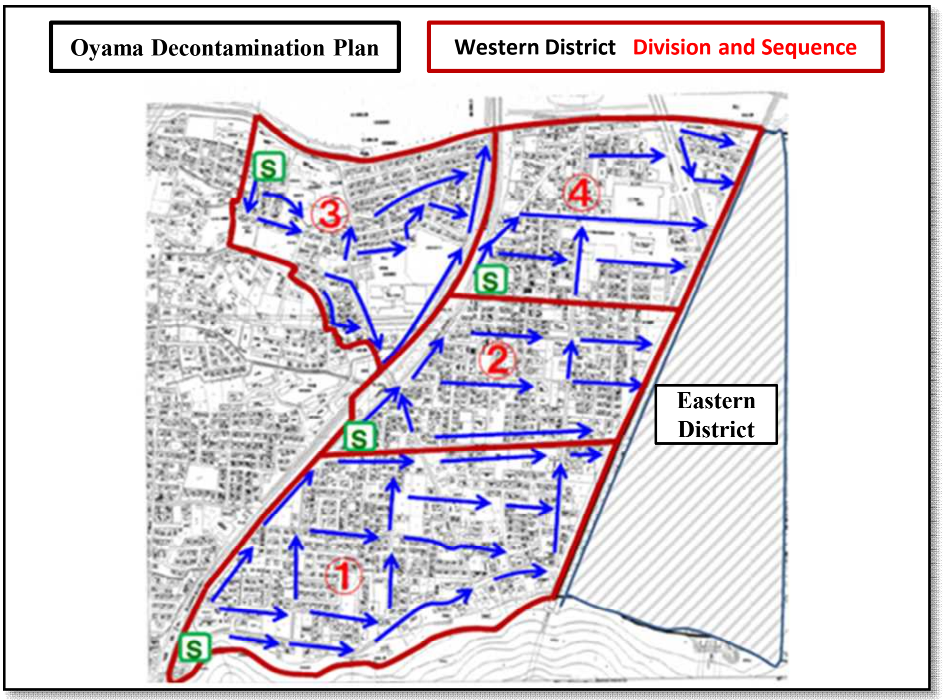


Figure 3-15 Decontamination plan taking water channels into account (Arrows indicate water flow lines)[87].

[86]Source: Kawauchi Village (October 1, 2013), Decontamination and dose control for villagers to return from full evacuation

[87]Source: Fukushima City (January 2013), Decontamination status in Fukushima City

3.3. Volume Reduction

3.3.1. Necessity of Volume Reduction

Wastes contaminated with radioactive materials and secondary wastes from decontamination works are produced in large quantities. Therefore, volume reduction is essential in the process of treatment and disposal of those wastes, in order to reduce the total amount of waste produced and to secure the storage sites. Combustible wastes contaminated with radioactive materials need to be stabilized to prevent their decomposition and emission of unpleasant odors. Intermediate treatment by incineration and other means can reduce the disposal volume to around one-twentieth to one-fifth of the original volume.

3.3.2. Volume Reduction Methods

There are many volume reduction methods from physical processes such as simple compression and crushing to chemical processes such as incineration and melting. Characteristics of each method are summarized in Table 3.2.

Table 3-2 Comparison of volume reduction methods[88]

Method	Volume reduction effect	Decontamination effect	Workability	Volume reduction rate (%)	Measures	Secondary waste
Melting	○	○	△	～99	Effluent gas	much
High Temperature Incineration	○	○	△	～90	Effluent gas	much
Low Temperature Incineration	○	△	○	50～80	Effluent gas	little
Drying	△	×	○	5～30	---	none
Cleaning	△	△	○	5～10	Wastewater	much
Classification	○	△	△	10～90	Wastewater	little
Compression	△	×	○	20～50	---	none
Shredding	△	×	△	～50	Dust	little

Each method of volume reduction is outlined below, being cited from the "Report on the surveys of off-site emergency responses associated with the accident at the Fukushima Daiichi Nuclear Power Station and the environmental restoration activities[88]."

（1） Melting method

The melting method reduces the volume of solid wastes by elevating their temperatures by means of plasma heating and other means up to super high temperatures (above 1,200 °C) and produces stable molten slag, while achieving a high decontamination effect by volatilizing most of the cesium including radioactive cesium(hereinafter referred to as "cesium") present. But, while the melting method volatilizes even silicic acids and other substances, treatment of a large quantity of secondary gaseous wastes becomes

[88]Source: Atomic Energy Society of Japan (December 2, 2013), Report on the surveys of off-site emergency responses associated with the accident at the Fukushima Daiichi Nuclear Power Station and the environmental restoration activities. (Table 3-3 has the same source.)

necessary. It is not practical to apply this method to the treatment of large quantities of contaminated wastes, in view of the work conditions at super high temperatures and the cost of fuel to melt the wastes.

（2） High temperature incineration

The high temperature incineration method reduces the volume of contaminated wastes by burning them (using heavy oil and other fuel) at temperatures up to around 1,000 °C in the air, volatilizing contained water and volatile oxides. Cesium volatilization is limited, but some cesium could be scattered and contaminate the upper part of incinerator or other parts depending on combustion temperatures and conditions. This method is well established and is able to treat massive wastes.

（3） Low temperature incineration

The low temperature incineration method burns wood and other materials in a reducing atmosphere of 600 to 800 °C, and then carbonizes the cinders for volume reduction. By volatizing carbon and hydrogen contents in the wastes, the volume reduction rate reaches around 90%, and no secondary wastes are produced because cesium volatilization is restrained. But, on the other hand, the cesium concentration in the residue becomes higher. This makes it necessary to give special consideration to the handling and storage methods depending on the concentrations of radioactive materials when radioactivity exceeds 8,000 Bq/kg, although the volume of wastes to be handled is decreased.

（4） Drying

Drying is carried out by heating wastes at the ambient temperature or below 100 °C. Big weight and volume reductions are achieved in the case of watery sludge. Trees and vegetation materials can be reduced in volume by drying to some extent, and no further secondary treatment is needed regarding decomposition and other undesirable changes.

（5） Washing

The washing method aims at reducing the volume of contaminated wastes by: dissolving the soluble materials by high-pressure water washing or immersing into water; separating fine particles from larger solids by suspending the fine particles in the water; and collecting the solids by solid/liquid separation such as filtration or other means. In this method radioactive cesium is dissolved into water and fine particles with adsorbed cesium are separated. The target objects can be decontaminated, but the water content of the waste collected is high and a secondary treatment is needed for volume reduction by drying and other means. Furthermore, the liquid collected contains a high concentration of cesium and also needs a secondary treatment for sorption and separation of the cesium.

（6） Classification

Classification is a method to separate and fractionate fine particles such as clay, to which cesium adheres, by sieves, and to reduce the volume of contaminated soil. There are two types of classification methods: the wet method uses a difference in sedimentation order in the water and the dry method uses sieving. The wet method gives effective separation, but the amount of secondary waste such as contaminated water increases. In contrast, the dry method is advantageous in producing no secondary waste, although it is a rough separation process. If a predetermined radioactivity decontamination effect is obtained in the separation by the particle size, the dry method is effective as a pretreatment method.

（7） Compression

The compression method is a method to reduce the volume by compressing contaminated wastes having low bulk densities with a press machine and other means. Because none of the radioactive materials are transferred, after being processed the wastes contain a higher density of radioactivity per unit volume. Therefore, it becomes necessary to give consideration to the handling and storage methods. This method is effective for application to contaminated wastes such as wood, trees and plant materials.

(8) Crushing

The crushing method is applied to contaminated wastes having shapes of a rectangle, circle or the like. The size of such contaminated wastes is reduced by crushing and densification, and thus the space for waste storage is reduced. No decontamination effect is obtained, since radioactive materials are not transferred by the crushing method. It is necessary to be careful not to disperse fine particles when crushing.

It should be noted that there are diverse wastes produced by radioactive contamination, and by decontamination, too. Therefore, suitability of individual methods of volume reduction depends on the target wastes for application. As shown in Table 3-3, there are cases in which sufficient effects cannot be obtained in volume reduction.

Table 3-3 Applicability of volume reduction methods for selected target items

Object	Volume reduction method	Weight loss	Cesium movement	Radioactivity	Volume reduction effect
Soil	Melting	yes	yes	decrease	large
	Incineration	yes	no	increase	large
	Cleaning	yes	yes	decrease	small
	Classification	yes	yes	decrease	medium
Wood	Incineration	yes	no	increase	large
	Low Temp. Incineration	yes	no	increase	medium
	Cleaning	yes	yes	decrease	small
	Compression	no	no	almost same	medium
Grass, Rice straw	Incineration	yes	no	increase	large
	Low Temp. Combustion	yes	no	increase	medium
	Cleaning	yes	yes	decrease	small
	Compression	no	no	increase	large
Concrete	Compression	no	no	almost same	small
	Shredding	no	no	almost same	medium
Sludge	Drying	yes	no	increase	medium
	Cleaning	yes	yes	decrease	small

3.3.3. Examples of Volume Reduction

A few examples of ongoing volume reduction activities of wastes are shown below.

(1) Crushing

Cut branches produced from the forest decontamination are bulky and need much space if they are packed as they are and they produce many waste containers. Therefore, a crushing facility can be used to crush cut branches for more effective packing in flexible containers. An example is practiced in Katsurao Village and other municipalities.

Figure 3-16　Branches cut down (left) in forest decontamination and a crushing facility (right)[89].

Figure 3-17　Interior views of a crushing facility: collection (left), putting in and crushing (center), and packing into flexible containers (right).

(2)　Chipping

The volume of contaminated wastes produced from decontamination work, such as branches and leaves, can be reduced by crushing into chips. Then, they can be stored more effectively in the temporary storage site of limited space. This method is being practiced in Date City and other municipalities.

[89] Source: Okumura-gumi Corporation (Figure 3-17 has the same source.)

Figure 3-18　Before (left) and after (right) chipping[90].

Figure 3-19　Chipping machine.

(3)　Compression / Packaging

Examples (1) and (2) above are intended to reduce the volume of wastes by crushing so that the materials become more tightly packed. There is another example of volume reduction by suction compression as shown below.

In this example, the volume is reduced by suction compression using compression storage bags. If ordinary packing bags are used, the suction openings tend to become clogged with leaves or the bags become torn by branches, but these difficulties can be overcome by using a special nozzle and a special compression storage bag, enabling the volume to be reduced to 1/3 to 1/2 of the original volume for combustibles such as fallen leaves, branches with leaves, grasses, etc.

The compression storage bags have an added odor killing function that controls odors from the combustibles arising around the temporary storage sites.

[90]Source: Division of Fukushima Prefecture Decontamination Measures (May 17, 2013), Decontamination Good Practices Casebook (Figure 3-19 has the same source.)

Figure 3-20 Before (left) and after (right) compression[91].

[91]Source: Taisei Corporation homepage
(http://www.taisei.co.jp/about_us/release/2013/1353289519671.html)