Design, installation, and maintenance of temporary storage sites for radioactive decontamination waste

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ABSTRACT

A number of temporary storage sites have been commissioned to contain soils and wastes generated from the decontamination works after the accident at Tokyo Electric Power Company’s Fukushima Dai-ichi Nuclear Power Plant. At these sites, volume reduction has been observed in the flexible container bags caused by the dehydration and decomposition of the decontamination waste inside. This situation leads to uneven settlement of the top of these flexible container bags in these temporary storage sites, and might result in problems such as leakage through top and bottom liners installed to contain these container bags. To deal with these problems immediately, the Geomembrane Technical Committee, Japan Chapter of International Geosynthetics Society has conducted deliberations and made reports on procedures for selection and installation of storage containers that are to prevent polluted water from leaking outside of storage sites, structures, and barrier materials, a new inspection procedure for seaming of cover geomembranes, installation of cover materials that are to counter uneven settlement of soil, and also temperature control procedures to prevent natural ignition of waste. This paper summarizes the deliberations and the procedures adopted.

Keywords: Fukushima Dai-ichi Nuclear Power Plant, decontamination waste, temporary storage site, barrier, maintenance

1 INTRODUCTION

On March 11, 2011, an earthquake and a subsequent tsunami occurred in Eastern Japan and resulted in significant damage to the Fukushima Dai-ichi Nuclear Power Plant. This damage caused radioactive contamination over a vast area around the eastern part of Japan. In the area with restricted access because of high radiation, and also other areas with a certain level of nuclide contamination, decontamination works have been conducted to reduce the radiation. The “decontamination” work involves the removal of soil, plants, trees, and any other materials contaminated with nuclides from the environment in order to reduce the radiation and decrease the risk of exposure. Through this decontamination process, large amounts of decontamination soil and waste have been generated. The volume of soil and waste is estimated to amount to at least sixteen million cubic meters. The waste soil and plants discharged through the decontamination process are first stored at a temporary storage site (for approximately 3 years), then at an interim storage facility (for approximately 30 years), and finally at a final disposal site, to be decided by the national government. Currently, because of the difficulty in reaching agreements for the construction of interim storage facilities, only temporary storage sites have been facilitated. There are currently more than sixteen thousand temporary storage sites.

The contaminated soil may contain grass and other organic materials that, when subjected to degradation, causes gas, heat, leachate generation, and reduction in volume. As a result, problems such as deposits of dust and rainwater on the top surface of the capping in the temporary storage sites, which require consequent solutions, exist. At the same time, various technical developments have been made in relation to geosynthetics. The Geomembrane Technical Committee, Japan Chapter of International Geosynthetics Society has conducted deliberations on the procedures for selection and installation of storage containers that can prevent contaminated water from leaking outside of storage sites, structures, and lining materials, new inspection procedure for seaming works of capping materials, installation of capping materials that adapt to
uneven settlement of soil, and also temperature control procedures to prevent natural ignition of waste. This paper summarizes the deliberations and the procedures adopted.

2 REGULATIONS

Following the Fukushima Dai-ichi Nuclear Power Plant accident, “Act on Special Measures Concerning the Handling of Environment Pollution by Radioactive Materials Discharged by the Nuclear Power Station Accident Associated with the Tohoku District-Off the Pacific Earthquake That Occurred on March 11, 2011” (Act on Special Measures Concerning the Handling of Radioactive Pollution) was established and enforced on January 1, 2012, to promptly reduce the impact of environmental pollution on human health and living environment caused by radioactive materials. The waste and debris from the decontamination procedure is stored at temporary waste sites maintained based on “Part 4: Guideline Regarding Waste” and “Specification of Decontamination and Related Works (Seventh edition)” stipulated by the Ministry of the Environment (2013). However, various problems have been observed at the actual sites, which are not mentioned in the guideline.

3 CONFIGURATION OF TEMPORARY STORAGE SITES

The wastes generated through decontamination works are sorted into biodegradable wastes and soils. Following storage at temporary storage sites, the waste is to be processed and stored at interim storage facilities. It is important to keep the decontamination waste from affecting the surrounding environment at these temporary storage sites. For most of the temporary storage, flexible container bags are used and the important functions of these storage containers are suppression of radioactive material leakage and reduction of waste volume. The containers of decontamination waste and soil are placed over the lining materials installed on compacted ground. Usually the containers are piled up three to five stages. On top of these piled up containers, another lining material is installed to prevent rainwater infiltration.

3.1 Storage container bags

Flexible container bags are used as temporary storage containers for the decontamination waste and, as stated above, the most important functions of these storage containers are suppression of nuclide-contaminated material leakage and volume reduction of biodegradable waste.

Figure 1 shows the variation in the containers of decontamination waste. Flexible containers roughly fall into waterproof or permeable types according to their intended use. It is important to choose the appropriate type in accordance with the characteristics of the contents. Flexible containers in which the inner bag material has cesium adsorption characteristics to drain sewage outside of the bag while holding radioactive cesium inside are currently under development.

Flexible containers are stipulated by JIS Z 1651. Weather resistant large sandbags are often used at sites as well, even though they are not classified as flexible containers.

Both flexible containers and weather resistant large sandbags are made of relatively thin material. Therefore, careful handling is required in order not to break the bags by dragging them filled with their contents or by damaging with pointed objects.

3.2 Bottom and top liners

Figure 2 illustrates the basic structure of a temporary storage site. On the ground of the storage site, to prevent decontamination waste and sewage from leaking outside of the yard, bottom lining materials must be installed beneath the storage containers. Further, to prevent infiltration of rainwater into the storage body, “capping” (top cover) with traditional geomembrane or air-permeable water-impermeable geomembrane on top of the mound of storage containers must be in place.

Figure 3 shows a classification for the lining material used at traditional waste landfill sites. At the temporary storage sites of the wastes from decontamination works, medium elastic geomembrane liners made from thermoplastic elastomer olefin and low density polyethylene are mainly used. The required basic properties are the same as those of the traditional geomembranes that are used in landfills. In some cases, geosynthetic clay liner or compacted clay liner is installed instead of the geomembrane. When long-term...
storage of decontamination waste with water is expected, applying a layer of clay-bentonite mixture or a layer of soil with cesium adsorption capability is particularly effective.

Top cover is required to be structured in a manner that prevents rainwater infiltration into the waste. A traditional geomembrane, air-permeable water-impermeable geomembrane, or a combination of both must be chosen in accordance with the characteristics of the waste.

The basic properties of top cover geomembrane are the same as those of the bottom lining geomembrane. Table 1 shows the basic properties of the air-permeable water-impermeable geomembrane.

![Fig. 2 Basic configuration of a temporary storage site (for organic wastes)](image)

![Fig. 3 Classification of seepage control material at final landfill sites](image)

### Table 1 Basic properties of the breathable waterproof membrane

| Specifications  | Basic Property             | Standard of Japan Geomembranes Technologies Association | Test method                              | Basis of standard                              |
|-----------------|-----------------------------|--------------------------------------------------------|------------------------------------------|------------------------------------------------|
| Seepage Control | Moisture Transmission       | 2,500 g/m² 24h or more                                  | JIS Z 0208 (40 degrees in Celsius, 90% RH) or JIS L 1099 (A-1) | Acceleration of heat control emission by transpiration |
|                 | Water permeation*           | 1.0×10⁻⁹ cm/sec or less                                 | JIS A 1218 (changing water head)         | -                                              |
| Tensile property| Tensile strength            | 345 N/5 cm or more                                      | JIS L 1908                               | Determined from the result of wind pressure    |
|                 | Joint                       | 15% or more                                            |                                          | -                                              |
|                 | Puncture resistance         | 500 N or more                                           | ASTM D 4833                              | Compliant with Specification of Protection mat of Japan Waste Management Association |

*Although there are water permeability and water resistance as index for hydraulic barrier, Japan Geomembranes Technologies Association chooses the former. Water permeability is not calculated from moisture transmission, but actual measured value compliant with water permeation test of soil.
Following installation of the storage containers at temporary storage sites, unevenness occurs on the top of the cover geomembrane according to the degree of compaction, dehydration, and degradation of the contents. As depicted in Fig. 4, rainwater settled in dents might cause failure of seaming of the capping material. Figure 5 shows an example of a countermeasure to this: Installation of geogrid soothes the subsidence caused by volume reduction of contents and prevents failure of the capping material.

4 INSTALLATION QUALITY CONTROL

4.1 Seaming inspection by thermal imaging

When a air-permeable water-impermeable geomembrane is applied as the top cover, it is difficult to inspect the joint part of the membrane via pressurized inspection or vacuum inspection owing to the gas permeability of the material. The currently available inspection method for the geomembrane seams on site is visual inspection or physical probing with an inspection rod on the joint part.

Application of thermal image remote sensing inspection, which has been used for inspection of the geomembrane seams at traditional waste landfill sites developed by Nakayama et al. (2014), is under consideration. The following is an example of an experiment in which this method was applied to air-permeable water-impermeable geomembrane and an example of a demonstrative experiment conducted.

This method enables inspection based on the thermal images of the surface of the air-permeable water-impermeable membrane (Fig. 6) or based on quantitative data of temperature of the seamed part, both of which produce records of inspection results.

Figure 7 shows a picture of an automatic welder and a schematic of the heat welding procedure. In seaming the air-permeable water-impermeable geomembrane by the welder, as the temperature of the welded part of the membrane rises, the temperature of the membrane surface on the joint part increases above that of the non-joint part by heat transfer. If the welding temperature is not sufficiently high because of foreign objects remaining on the joint surface or problems on the welder, the joint could fail. In this case, the surface temperature of the breathable waterproof membrane is lower than that of the normal joint part. By acquiring a thermal image of the surface of the membrane with a thermal infrared image processor, joint failure can be detected easily and promptly.

4.2 Experiments

We used breathable waterproof membrane CRE500G as test pieces and acquired thermal images of these test pieces while seaming them with an automatic welder with a heating plate and smooth rolls for single seam. In addition, we prepared four conditions, as shown in Table 2, to observe the difference in the surface temperature of the joint part. Following the joining, we conducted tensile strength tests on the joint part.

Figure 8 shows the results of tensile strength tests—the relation between tensile strength at the shear...
fracture on the seamed part and the surface temperature. Under gusty winds such as a wind speed of 30 m/s, the shear stress on the seamed part could reach a maximum

| Experimental conditions | Run No. | 1 | 2 | 3 | 4 |
|-------------------------|--------|---|---|---|---|
| **Experimental condition** | indoors | indoors | indoors | outdoors |
| **Initial temperature** | 9°C | 30°C | 35°C | 60°C |
| **Welding pressure** | 700 | 700 | 700 | 700 |
| **Welding speed (m/min)** | 1.5 | 1.5 | 1.5 | 1.5 |
| **Roller type** | Single | Single | Single | Single |
| **Welding temperature (°C)** | 100 | 100 | 100 | 100 |
| | 150 | 150 | 150 | 150 |
| | 200 | 200 | 200 | 200 |
| | 250 | 250 | 250 | 250 |
| | 300 | 300 | 300 | 300 |
| | 350 | 350 | 350 | 350 |

Table 2 Experimental conditions

![Figure 8](image)

Fig. 8 Relation between shear tensile strength on joint part and surface temperature of joint part

![Figure 9](image)

Fig. 9 Relation between threshold temperature and initial surface temperature of membrane

of 325 N/5 cm, and so we set the benchmark strength to 400 N/5 cm for this thermal image remote sensing inspection. The temperature of the seamed surface at which the shear stress on the joint part reaches 400 N/5 cm was set as the benchmark temperature (hereafter called the “threshold temperature”). If the surface temperature of the joint part is higher than that of the threshold temperature, the test piece is judged successful; otherwise, if the temperature is lower than the threshold, the piece is judged a failure. The threshold temperature varies according to the conditions such as initial surface temperature of the breathable waterproof membrane (hereafter called the “initial surface temperature of the membrane”), and sunshine conditions. The relation between threshold temperature $y$ (degrees in Celsius) and initial surface temperature of membrane $x$ (degrees in Celsius) is shown in Fig. 9; it leads to formula (1):

$$y = 0.6346x + 20.95$$

(1)

4.3 Pilot test

We conducted a demonstrative experiment in Soma city, Fukushima prefecture from August 22 to 25, 2015 to simulate the applicability of this method to temporary storage site.

The initial surface temperature of the membrane in joining (temperature of the non-joint part indicated inside of the sub-window with the blue frame for surveillance in Fig. 6) was 40 to 42 degrees in Celsius. This figure is assigned to $x$ in formula (1) to calculate threshold temperature $y$. Comparing the threshold temperature with the surface temperature on the joint part (indicated as the temperature in the window with the white frame in Fig. 6), the process is deemed successful if the temperature of the joint part is equal to or higher than the threshold temperature. An example of a result obtained for thermal image remote sensing inspection on the joint part of the breathable waterproof membrane is shown in Fig. 10. The bold line is the surface temperature of the joint part whereas the dotted line is the threshold temperature in Fig. 10. Because the surface temperature of the joint part across the area is higher than the threshold temperature, this joint part is deemed a success.

This demonstrates the effectiveness of the proposed inspection method on the joint part of the air-permeable water-impermeable geomembrane.

![Figure 10](image)
5 TEMPERATURE MONITORING FOR MAINTENANCE

Because the main purpose of maintenance is to prevent nuclide-contaminated waste from leaking outside of the temporary storage sites and accidents such as fire, the role of maintenance is important. To avoid these issues in advance, constant surveillance is required to monitor whether each facility is performing its functions properly. An example of the temperature dispersing measurement from outside the temporary flammable waste storage sites under consideration is given below.

A thermal infrared camera installed in the position illustrated in Fig. 11 was used to measure the temperature of the entire site and record images and data with elapsed time.

To evaluate the integrity of the air-permeable water-impermeable membrane, we simulated a defective portion, as shown in Fig. 12, and inspected the temperature changes around the area. After repairing the portion, we inspected the temperature changes around the portion and evaluated the soundness and confirmed that the repair was effective.

Because the purpose of this inspection is to prevent fire accidents caused by heat generation arising from microbe degradation of organic waste, the temperatures were measured immediately before dawn, when the temperature difference between the defect portion and the normal portion is assumed to be the greatest throughout the day. However, it is also important to measure temperatures during the daytime when heat generation arising from microbe degradation and absorbed heat from direct sunlight heightens the risk of natural ignition.

6 CONCLUSIONS

In this paper, we reported on the variations in the design, installation, and maintenance at temporary storage sites to prevent contaminated water from leaking outside. Decontamination waste is constantly being accumulated at the temporary storage sites. Consequently, various problems, inherent or revealed, other than those reported in this article, exist, and so continuous technical developments are urgently needed.

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