Radioactivity decontamination in and around school facilities in Fukushima

Jun SAEGUSA*, Akihiro TAGAWA*, Hiroshi KURIKAMI*, Kazuki IIJIMA*, Hideki YOSHIKAWA*, Takayuki TOKIZAWA*, Shinichi NAKAYAMA* and Junichiro ISHIDA*
*Japan Atomic Energy Agency
6-6 Sakaemachi, Fukushima-shi, Fukushima 960-8031, Japan
E-mail: saegusa.jun@jaea.go.jp

Received 30 October 2015

Abstract
Approximately two months after the Fukushima nuclear accident, the Japan Atomic Energy Agency (JAEA) led off a series of demonstration tests to develop effective but easily applicable decontamination methods for various school facilities in Fukushima. This effort included (1) dose reduction measures in schoolyards, (2) purification of swimming pool water, and (3) removal of surface contamination from playground equipment. Through these demonstration tests, they established practical methods suitable for each situation: (1) In schoolyards, dose rates were drastically reduced by removing topsoil, which was then placed in 1-m-deep trenches at a corner of the schoolyard. (2) For the purification of pool water, the flocculation coagulation treatment was found to be effective for collecting radiocesium dissolved in the water. (3) Demonstration tests for playground equipment, such as horizontal bars and a sandbox wood frame indicated that the decontamination effectiveness considerably varied depending on the material, paint or coating condition of each equipment piece. These findings were summarized in reports, some of which were compiled in local/national guidelines or handbooks for decontaminating the living environment in Fukushima.

Key words: Fukushima nuclear accident, Decontamination, Environmental restoration, Radiation measurements, Radioactive cesium, Water treatment

1. Introduction
The Fukushima nuclear accident in March 2011 resulted in the release of a considerable amount of fission and activation products, particularly volatile iodine and cesium, into the environment around the Tohoku region of Japan. The total amounts of $^{131}$I and $^{137}$Cs released into the atmosphere were reported to be in the order of $10^{17}$ and $10^{16}$ Bq, respectively (Chino et al., 2011; Povinec et al., 2013). Because $^{131}$I has a relatively short half-life ($t_{1/2}$) of 8.0 d, radioactive cesium ($^{134}$Cs ($t_{1/2}$: 2.1 y) and $^{137}$Cs ($t_{1/2}$: 30 y)), hereinafter collectively referred to as radiocesium, was the dominant contaminants.

A wide range of remediation actions have been undertaken with the aim of decontaminating affected areas in Fukushima. Among them, the decontamination of school facilities was an urgent necessity and a high priority to enable a secure environment for children’s education to be restored (IAEA, 2011).

The Japan Atomic Energy Agency (JAEA), in concert with local communities, proceeded with decontamination demonstration tests for the various school facilities such as schoolyards, swimming pools, playground equipment, and their peripheries. The primary objectives of these demonstrations were to acquire practical data on the effectiveness of each method and knowledge of the required manpower, cost, and radiation protection measures during the work. The obtained data and knowledge had to be immediately studied and reported to promote smooth technical transfer and field operations in a number of schools in Fukushima. This can be achieved through multiple processes with the involvement of local people, including volunteers, school teachers, business operators, municipality administrations, and national authorities. This paper reviews these demonstrations at schools in Fukushima.
2. Topsoil removal of schoolyards

2.1 Outline

In May and June 2011, decontamination tests were performed at schoolyards at the National Fukushima University Kindergarten and Junior High (JH) School (Yoshikawa et al., 2012; Kurikami et al., 2013). At each schoolyard, the topsoil down to about 5 cm from the surface was removed as a countermeasure to decrease ambient dose rate above the ground.

The removed soil, with radiocesium concentrations as high as 85 kBq kg\(^{-1}\), was put into two 1-m-deep trenches in a corner of the JH schoolyard. The trenches were covered with 50 cm of uncontaminated soil excavated from a deeper part of the schoolyard and with soil from another uncontaminated area. The bottom and sides of the trenches were lined with water-sealing sheets.

2.2 Measurement of dose rates

Before and after the soil removal, dose rates at 1, 50, and 100 cm above the ground surface were measured and compared at the predetermined locations in each schoolyard (Kindergarten: 12 points, JH School: 109 points, at 10-m intervals for both (Fig. 1)) and their peripheral locations. The dose rates were measured with energy-compensated NaI(Tl) survey meters (Hitachi Aloka Medical, Ltd., TCS-161 and TCS-172B). The average dose rate measured at the entrance hall of the JH School was in the range between 0.10 and 0.18 \(\mu\)Sv h\(^{-1}\) depending on the survey meters used. This was subtracted from each on-site data as a background dose rate.

In Fig. 2, histograms of measured dose rates before the decontamination are shown for the JH schoolyard. The dose rates at 100 cm above the ground surface were 2.0–3.0 \(\mu\)Sv h\(^{-1}\), whereas those at 50 cm above and at the ground surface (1 cm) were 2.0–3.6 \(\mu\)Sv h\(^{-1}\) and 1.7–4.5 \(\mu\)Sv h\(^{-1}\), respectively.

Table 1 summarizes the average dose rates measured at each location. The dose rates at the Kindergarten significantly decreased from 2.8 \(\mu\)Sv h\(^{-1}\) to 0.22 \(\mu\)Sv h\(^{-1}\) on average at 50-cm-high points, and at the JH School also decreased from 2.5 \(\mu\)Sv h\(^{-1}\) to 0.15 \(\mu\)Sv h\(^{-1}\) at 1-m-high points. These data also revealed that dose rates were higher near the ground surface before the decontamination, but vertically uniform after the work, which implicated the contribution of radiation coming from a distant location.

2.3 Radioactivity concentration of the soil

The schoolyard soil was sampled at the northwest corner of the JH schoolyard. The concentration of radiocesium was evaluated by gamma-spectrometry analyses with a HPGe
detector and determined to be 85,000 Bq kg\(^{-1}\) \((134\text{Cs}: 39,000 \text{ Bq kg}\(^{-1}\), \(137\text{Cs}: 46,000 \text{ Bq kg}\(^{-1}\), as of 25 May 2011) for the soil sampled at the ground surface. The concentration decreased to 1,400 Bq kg\(^{-1}\) for the soil sampled at depths of 0–5 cm. Below 5 cm, the radioactivity concentration was less than the minimum detectable activities (MDA) of approximately 40 Bq kg\(^{-1}\) at a 95% confidence level.

\(^{131}\text{I}\) was also detected in the surface soil. Its concentration was 2,100 Bq kg\(^{-1}\) as of the same day.

### 2.4 Follow-up monitoring

In order to check the continuity of the decontamination effect, follow-up measurements were implemented on the exact locations each dose rate was measured. Figure 3 shows the relationship of dose rates (at 100 cm high above the ground surface) just after the topsoil removal (9 June 2011) and those measured one year thereafter (29 May 2012). Overall, the dose rates in 2012 were less than what was expected, i.e., below the solid line in the figure that corresponds to the physical decay of radiocesium.

Around the Kindergarten and JH schoolyards, there is a girdle of trees including tall ones as high as 15 meters (see Fig. 1). From late July 2011 until the beginning of the next month, Fukushima University performed large-scale cuttings and clippings of these plantings as a countermeasure for dose reduction in the campuses. According to the university (Fukushima Univ. website, 2011), the dose rates at both schoolyards decreased approximately by 10%–20% in the corresponding period, and this is believed to be a cause of the less-than-expected dose rates.

By the follow-up monitoring, it was thus confirmed that there was no obvious recontamination at either schoolyard.

### 3. Water treatment and discharge of swimming pool water

#### 3.1 Outline

After the accident, many schools in Fukushima suspended pool water discharge. Fukushima is a relatively suburban area and in many cases water is directly discharged into a waterway that leads to paddy fields for rice farming. In order to mitigate both the scientific and social impact of the discharge, JAEA reviewed the existing flocculation and coagulation methods for water purification and developed a practical method on the basis of on-site demonstration tests (JAEA, 2012; Saegusa et al., 2013). The demonstration tests were conducted at the eight school pools listed in Table 2. These pools have various characteristics in terms of their capacity, contamination level, amount of soil particles and other tangible factors.
Table 2  List of outdoor swimming pools where decontamination demonstrations were conducted.

<table>
<thead>
<tr>
<th>Pool</th>
<th>Period of demonstration (year: 2011)</th>
<th>Size of pool (m$^3$)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) The National Fukushima Univ. Kindergarten</td>
<td>Jul. 13–17</td>
<td>17</td>
<td>Large amount of falling leaves</td>
</tr>
<tr>
<td>(2) The National Fukushima Univ. Junior High School</td>
<td>Jul. 22–29</td>
<td>350</td>
<td>Sludge consists of relatively fine grains</td>
</tr>
<tr>
<td>(3) Date City Tominari Elementary School</td>
<td>Jul. 2–12</td>
<td>260</td>
<td>Large amount of algae, falling leaves</td>
</tr>
<tr>
<td>(4) Date City Hashirazawa Elementary School</td>
<td>Aug. 2–5</td>
<td>240</td>
<td>Large amount of algae, falling leaves</td>
</tr>
<tr>
<td>(5) Date City Shoyo Junior High School</td>
<td>Aug. 9–12</td>
<td>450</td>
<td>Pool made of reinforced plastic</td>
</tr>
<tr>
<td>(6) Date City Tsukidate Elementary School</td>
<td>Aug. 23–25</td>
<td>370</td>
<td>Strong smell from sludge</td>
</tr>
<tr>
<td>(7) Date City Hobara Elementary School (Small)</td>
<td>Aug. 26, 29–Sep. 2</td>
<td>150</td>
<td>A volume of algae growth</td>
</tr>
<tr>
<td>(8) Date City Hobara Elementary School (Large)</td>
<td>Aug. 26, 29–Sep. 2</td>
<td>300</td>
<td>Clear upper portion, small amount of algae</td>
</tr>
</tbody>
</table>

3.2 Method

There is no legal standard on the water quality for the discharge of pool water. However, setting a reference value on radioactivity concentrations is often helpful for decision-making processes among the relevant communities. In the present tests, the reference value was set at 200 Bq L$^{-1}$ in terms of radiocesium, which corresponded to the “provisional regulation values” for drinking water, which was set by the central government (MHLW website, 2012). For water with radioactivity concentrations above the reference level, the flocculation and coagulation process was applied.

The pool water was pumped into 1-m$^3$ tanks in which zeolite powder and a flocculant were added for trapping radiocesium, which was the only gamma-emitting radionuclide detected (Fig. 4 (a)). The supernatant was discharged if the concentration was less than the targeted level. In addition, hydrogen-ion concentration of the discharging water was continuously monitored and controlled by reference to the national standard on effluent. The radioactive residue was collected and stored in a temporary storage space (Fig. 4 (b)).

Fig. 4  (a) Treatment of contaminated water using 1-m$^3$ tanks and (b) temporary storage of radioactive residue collected from the pool.
3.3 Results

The results showed that water with a concentration more than a few hundred becquerels per liter was readily purified to less than 100 Bq L\(^{-1}\). The radioactivity concentrations of \(^{89}\)Sr, \(^{90}\)Sr, \(^{238}\)Pu, and \(^{239+240}\)Pu in the water were all less than each isotope’s MDA (99.7% confidence level): 2, 0.1, 0.002, and 0.002 Bq L\(^{-1}\), respectively. The ambient dose rates around the temporary storage space were slightly elevated; however, the total increase was up to 30% of the original dose rates when the residue was shielded with sandbags containing uncontaminated soil.

3.4 Radioactivity budget

On the basis of the radioactivity data of supernatant pool water, residue, and a water balance trend, the overall deposition density of radiocesium was evaluated for a pool at the Date City Tsukidate Elementary School (Saegusa et al., 2014). The average radiocesium concentrations of the water and residue were quantified as 170 Bq L\(^{-1}\) and \(3.6 \times 10^5\) Bq kg\(^{-1}\) (wet condition, total weight: 185 kg), respectively. With these data, the deposition density of radiocesium was determined to be 0.32 ± 0.03 MBq m\(^{-2}\) \((k=1)\) as of 25 August 2011.

These values are consistent with those measured by the airborne surveys, in-situ Ge surveys, and soil samplings at neighboring locations in the Tsukidate district (MEXT website, 2013; Sanada et al., 2014; Saito et al., 2015).

Considering the surface area of the pool (415 m\(^2\)), the total deposition in the pool was 130 MBq and that in the supernatant water was 62 MBq. This means that approximately 50% of the radiocesium was retained in the water either in the form of ions or with suspended solid particles, i.e., fine clay and algae, and the remainder existed in the residue.

4. Decontamination of other school facilities

4.1 Outline

A broad range of investigations was performed to develop effective but easily applicable decontamination methods for other school facilities such as playground equipment (slides, swings, horizontal bars), sandpits, flower gardens, fences, and drain systems (Tagawa et al., 2012; Kurikami et al., 2013). The methods included brushing (with/without water), washing (which sometimes involved high-pressure water jets), choices of detergent, and wiping with different types of cloth.

4.2 Measurements of surface contamination

The surface contamination levels of various playground equipment pieces were monitored before and after decontamination by a GM surface contamination survey meter (Hitachi Aloka Medical, Ltd., TGS-133). The entrance window of a GM probe was set near the surface of each piece with a separation distance of about 1 cm. The background count rate was estimated by placing a 7-mm-thick lead plate between the GM probe and a target. An example of the decontamination effectiveness for horizontal iron bars (Fig. 5) is summarized in Table 3. In this case, four types of methods (water washing, washing with neutral detergent, sanding with sandpaper, and washing with orange-oil) were compared, and it was found that in

![Fig. 5 An example of horizontal bars, with schoolchildren’s parents who are engaging in the decontamination work at a school.](image)

<table>
<thead>
<tr>
<th>Count rates by surface contamination monitor</th>
<th>Water washing</th>
<th>Neutral detergent</th>
<th>Sandpaper</th>
<th>Orange-oil detergent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross (cpm)</td>
<td>200</td>
<td>180</td>
<td>230</td>
<td>270</td>
</tr>
<tr>
<td>Net (cpm)</td>
<td>100</td>
<td>80</td>
<td>130</td>
<td>170</td>
</tr>
<tr>
<td><strong>After</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross (cpm)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Net (cpm)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Reduction rate (%)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
any case, the reduction rates of the count rates were 100%. This suggests that the contamination on the iron bars can be completely removed by wiping out a surface. In Table 4, another example is shown for a wood frame that surrounds a sandpit (Fig. 6). In the case of simple water washing, the reduction rate was only 36%, whereas it increased up to 99% by sanding with an electric sander. As for other equipment, the effectiveness and simplicity of each method considerably varied depending on the quality of the material, paint/coating condition, and assembly structure of each facility.

### 5. Dissemination of outcomes

JAEA initiated these activities at the early stage of the large-scale remediation actions currently undertaken. The results of these activities were not only summarized in reports, but some of them were recorded as video clips and delivered on the Internet in order to facilitate the understanding of specific procedures and safety measures as required. Also, it has been dispatching its staff members to schools and providing site-specific technical advice and support to decontaminate these facilities effectively (Fig. 5).

Much of the data and knowledge obtained were made available to local/national authorities and subsequently were compiled into their guidelines or handbooks. Note that these demonstration tests were achieved with the commitment of local people, including teachers, parents, and municipality staffs who still are making efforts to reduce dose rates in the local infrastructure.

In addition to these decontamination demonstrations, comprehensive demonstrations at various locations, including farmlands and forests, were conducted by JAEA within the framework of the “Decontamination Pilot Project.” The project was executed at model zones in 11 municipalities in Fukushima, totaling 209 hectares in area. The outline and results of the project can be found in a report (JAEA, 2015).

### References


JAEA, Remediation of Contaminated Areas in the Aftermath of the Accident at the Fukushima Daiichi Nuclear Power Plant.


