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REVIEW
Development and Adaptability of a Topsoil Removal Machine for Decontaminating Peripheral Areas of Agricultural Land

Mitsuru HACHIYA[1]*, Daisuke MIYAMA[1], Masamoto CHIBA[1], Masahiro MIYAZAKI[1], Hideyuki ICHIKI[1], Yoshiji OCHIAI[1], Masamitsu TAKAHASHI[1], Hisashi HOSOKAWA[2], Kyo KOBAYASHI[2], Ryuzo NAKAMURA[3], Tetsuaki HAYASHI[3], Tsutomu TODA[4] and Kazuo KOTAKE[5]

[1] NARO Bio-oriented Technology Research Advancement Institution (Saitama, Saitama 331-8537, Japan)
[2] NARO Agricultural Research Center (Tsukuba, Ibaraki 305-8666, Japan)
[3] KUBOTA Corporation (Sakai, Osaka 590-0823, Japan)
[4] SASAKI Corporation (Towada, Aomori 034-8616, Japan)
[5] YANMAR Co., Ltd. (Osaka, Osaka 530-8311, Japan)

Abstract
Restoration and reconstruction are the largest and most pressing tasks following the nuclear accident at Fukushima. In this paper we address the task of reducing external exposure to radiation from radioactive material that has accumulated in agricultural land or its peripheral areas, and report on the features of a machine developed to decontaminate the peripheral areas of agricultural embankments and roads, as well as the on-site testing results. Based on the results of analyzing the vertical distribution of radioactive Cs concentration in the soil, we set the removal depth of the machine to 5 cm and proceeded with operation. In terms of usability and the decontamination effects provided by the embankment topsoil removal machine, we achieved a field capacity of 4.4 a/h and reduced the concentration of radioactive Cs and the air dose rate after treatment by about 80%. And based on the test results of the agricultural road surface stripping machine, a field capacity of approximately 0.83 a/h and an extremely high reduction rate of about 90% were achieved after stripping and removal treatment of the soil. Furthermore, the results of surveying the dust exposure status as an operating environment factor related to worker safety (as pertaining to developed machinery) suggested that the fully enclosed construction of the operating section of both machines apparently contributed to reducing the scattering of dirt, sand and dust that degrade the surrounding environment during decontamination operation.

Discipline: Agricultural machinery
Additional key words: radioactive material cesium, air dose rate, dust concentration, field test

Introduction

The hydrogen explosions in the accident that occurred at the Fukushima Daiichi Nuclear Power Plant in conjunction with the Great East Japan Earthquake on March 11, 2011 released a large quantity of radioactive material, resulting in radioactive contamination of a wide area centered in Fukushima prefecture, and causing a major impact on Japan's agriculture, forestry, and fishing industries. This marked the first time that Japan had experienced large-scale radioactive contamination of agricultural land, thus making restoration and reconstruction the largest and most pressing tasks following the nuclear accident. Various institutions have been earnestly

This paper reports the results obtained in the joint project on "Development of Technologies to Remove and Reduce Radioactive Material from Forests and Facilities Peripheral to Agricultural Land" sponsored by the Ministry of Agriculture, Forestry and Fisheries (MAFF).
*Corresponding author: e-mail mhachiya@affrc.go.jp
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surveying and researching the soil contamination status and other factors in surrounding areas, and attempted to develop technologies for restoring the large areas of agricultural land that form the basis of food production.

Two perspectives need to be incorporated into efforts toward addressing the problem posed by contaminated agricultural land: 1) external exposure to radiation from radioactive material that has accumulated in agricultural land and causeways, agricultural roads, canals, surrounding forests, etc., and 2) internal exposure from consuming agricultural produce contaminated by radioactive material. Both forms of exposure must be reduced at the same time. To reduce external exposure, decontamination measures are taken to reduce the air dose rate. To reduce internal exposure, absorption countermeasures are taken to reduce the migration of radioactive material into agricultural produce.

In this paper we address the task of reducing external exposure, and report on the features of a machine developed to remove contaminated topsoil for decontaminating areas peripheral to agricultural land, as well as the on-site testing results.

1. Development Background of the Machine for Decontaminating Areas Peripheral to Agricultural Land

Ten years after the accident at the Chernobyl Nuclear Power Plant in 1986, radioactive material that fell on agricultural land was still considered to have high concentrations in the topsoil (INTERNATIONAL ATOMIC ENERGY AGENCY, 2006; Ministry of the Environment, 2012). Assuming that the recent accident in Fukushima presents the same situation, removal of the topsoil should enable restoration of the contaminated agricultural land to a usable condition. The key point is reducing the concentration of radioactive material by carrying all the removed soil away from cultivation areas. At the same time, however, another requirement is minimizing the volume of soil removed as it must be processed as waste soil.

In making a full-fledged start in fiscal 2012 to decontaminate agricultural land, the Ministry of Agriculture, Forestry and Fisheries (MAFF) established a research project (under a third supplementary budget for fiscal 2011) called “Development of Technologies to Remove and Reduce Radioactive Material from Forests and Facilities Peripheral to Agricultural Land.” As part of this project, a public appeal was made for the “development of technologies for decontaminating agricultural facilities, causeways, and agricultural roads, etc.” A Consortium for Agricultural Periphery Decontamination was organized to apply in response to the appeal under the leadership of the National Agriculture and Food Research Organization (NARO) Bio-oriented Technology Research Advancement Institution and its comprising agricultural machinery manufacturers, the NARO Agricultural Research Center, and the NARO Institute for Rural Engineering. The consortium’s application was accepted in late December 2011.

This task targeted the development of four mechanical technologies for economically and safely removing radioactive material concentrated in the topsoil of respective agricultural peripheral areas of causeways, embankments, agricultural roads, and drainage ditches, and testing their applicability. In fiscal 2012, the consortium supplied prototypes for these technological developments and conducted ongoing trials on-site under the project for “Development of technologies for reducing and removing radioactive material from agricultural land and forests” (Miyazaki M. 2012). Among the machines for the four areas above, we give an overview of the machine developed for removing topsoil on embankments and the machine for removing the top layer of soil on agricultural roads.

Table 1. Specifications of embankment topsoil removal machine

Item	Specifications
Size (mm)	2,000 (L)×2,100 (W)×1,050 (H)
Mass (kg)	460
Effective width (mm)	1,600
Category of connecting device	three-point hitch (category 2)
Adaptive tractor (kW)	55-77
Removal depth (mm)	30, 50
Working speed (m/s)	0.06-0.42
Excavating blades	95-mm pitch, 34 sets

2. Features of the Topsoil Removal Machine for Decontaminating Areas Peripheral to Agricultural Land

The development concept of the topsoil removal machine for decontaminating areas peripheral to agricultural land included 1) realizing a system of decontamination operation on the front lines of agricultural production that can be undertaken as a farming operation or an extension thereof, 2) a system with wide–ranging operational applications, and 3) a system developed in a short timeframe that combines and improves existing technologies, in principle. Development was conducted based on these conditions.

(1) Embankment topsoil removal machine

The embankment topsoil removal machine that we developed is to be mounted directly on a tractor with engine output of 55 kW or higher, and equipped with an external hydraulic outlet via a three-point hitch (category 2) (Toda, T. and Maeyama, T., 2012). (See Table 1 and Fig. 1.) We conducted field surveys on the dimensions and tilt angles of embankments, and then fixed the specifications of settings for the above machine based on the survey results. This implement can be offset to the right side of the tractor, and can rotate around the axis parallel to the traveling direction by 50 degrees.

Based on these results, the machine will still be able to remove topsoil provided that the angle is within the above range, even if the embankment face is inclined vertically relative to the tractor's traveling surface. The effective working width is 1,600 mm and two removal depth settings are provided (3 cm and 5 cm). The removed topsoil is discarded from the side of the operating section to form a row of discarded soil that can easily be collected by a front loader or similar device. A roller to stabilize and maintain the respective set removal depths, a total of 34 sets of excavating blades arranged at a 95-mm pitch in a form that enables flat excavation, and a screw conveyor that carries topsoil removed by the excavating blades out to the left side of the operating section are attached to the three rotating axles provided in the operating section perpendicular to the traveling direction.

(2) Agricultural road surface stripping machine

This machine is based on an improved version of the stone crusher of FAE in Italy (model No. STC125). A stone crusher is an agricultural machine that crushes and deposits small stones in a field. We based our machine on the smallest type of this stone crusher (Kotake, K. et al. 2012). (See Table 2 and Fig. 2.)

The machine that we developed is intended for connecting directly via a three-point hitch (category 2) to a tractor with an engine having output of at least 66 kW. The machine is resilient to the effects of an uneven ground surface, and recommended for use with a half-track tractor that can maintain stable traction power and tilling depth. The machine has a total width of 1,760 mm (for an effective working width of 1,340 mm), but due to a working width that is narrower than the lateral width of the tractor crawler, the machine has low applicability for the shoulders of agricultural roads. We therefore improved the machine by enabling it to be offset to the left or right.

The offset amount can be changed in four steps up to a maximum of 260 mm. The machine excavates the road surface and gravel by means of rotors that rotate in the direction opposite the traveling direction. The excavating blades are made of super hard tungsten carbide alloy. Stones up to 30 cm in diameter can be crushed between the excavating blades and receiver blades to around 3 cm in diameter. The crushing grade can be adjusted by changing the degree of the rear cover's opening. When adjusting the tilling depth, the three-point hitch is adjusted to the appropriate height, and the length of the top link is adjusted so that the angle of the sled becomes 0°.

Table 2. Specifications of agricultural road surface stripping machine

Item	Specifications
Size (mm)	1,500 (L)×1,760 (W)×1,360 (H)
Mass (kg)	1,850
Effective width (mm)	1,340
Category of connecting device	three-point hitch (category 2)
Adaptive tractor (kW)	66-81
Removal depth (mm)	0-300
Working speed (m/s)	0.06-0.19
Excavating blades	30 sets

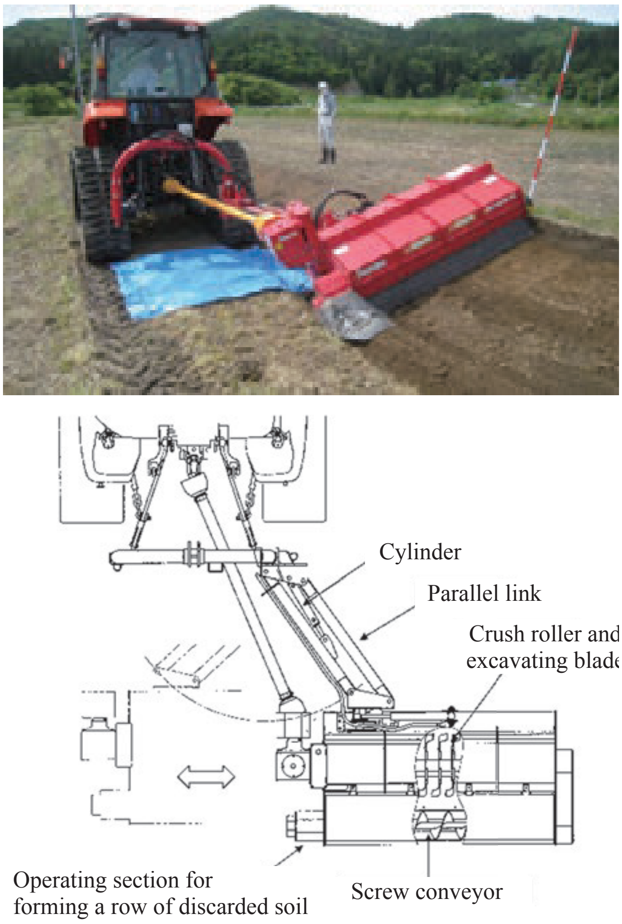
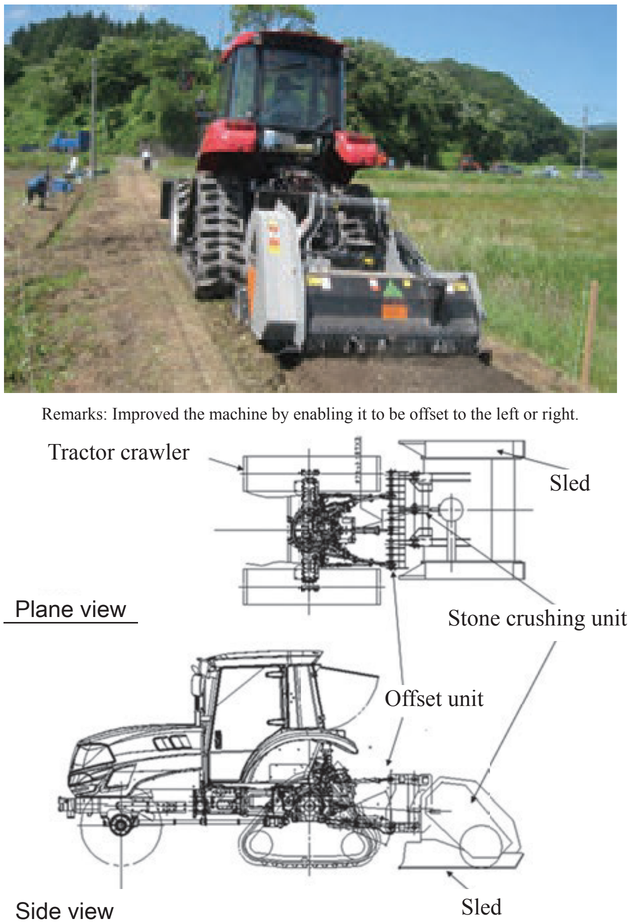


Fig. 1. External appearance (top) and top view (bottom) of embankment topsoil removal machine



Remarks: Improved the machine by enabling it to be offset to the left or right.

Fig. 2. External appearance (top) and overview (bottom) of agricultural road surface stripping machine

3. On-site testing of the developed machinery's applicability

To test the applicability of the developed machinery described above, we conducted field testing in the Itamizawa district and the Iitoi district of Iitate village in Fukushima prefecture in mid-March and late June of 2012. In the tests, we asked local farmers to serve as operators of the machinery. The test items were the work rate, topsoil cross-sectional profile (operational accuracy), concentration of radioactive material in the topsoil, air dose rate, and concentration of dust in the working environment.

The topsoil profile of the embankment was scanned at 0.5-cm intervals using a profile measuring device (NARO-IAM/BRAIN prototype) equipped with a laser sensor, and the height of the ground surface was calculated by taking measurements at three places along the traveling direction. For the profile of the agricultural road surface, we stretched a surveying leveling line across stakes set on both shoulders of the road, and used a ruler to measure the vertical distance from the line to the surface at lateral intervals of 10 cm with 0.5-cm resolution at three places along the traveling direction, as was done with the embankment.

Analysis of the concentration of radioactive material was outsourced and only conducted during the March testing time. The analysis was conducted for the radioactive material cesium (Cs), specifically ^{134}Cs (with a half-life of 2.2 years) and ^{137}Cs (with a half-life of 30 years). To measure the ambient dose rate we used a scintillation survey meter (Hitachi Aloka Medical TCS-172B) to sample the air at heights of 1 cm and 1 m above the surface. The measurement at 1 cm above the surface was taken by combining a collimator method (where the survey meter's detector was covered by a lead shield to block out radiation from the surrounding air, so as to measure only the radiation released from the measurement target ground surface) and a non-collimator method.

To measure the concentration of dust, digital dust meters (SIBATA LD-5: light dispersal type) were also installed near the operator's mouth and along the periphery of the working area. A low-volume sampler (SIBATA LV-40BR+A) was used to make measurements in parallel.

(1) Usability and decontamination effects of the embankment topsoil removal machine

The test tractor was a 58.8 kW half-track model (SMZ805-PC made by Kubota Corporation). To ascertain the contamination status of the testing site—an embankment beside a field in the Itamizawa district of Iitate village (soil type: crumbly black topsoil)—we sampled soil at a depth of 10 cm perpendicular to the slope surface at 5-cm intervals, and then measured the vertical distribution of radioactive Cs concentration in the soil. The analysis results of this sampling revealed that the ratio of radioactive Cs (^{134}Cs and ^{137}Cs) deposited in the first layer of topsoil at a depth of 5 cm was about 73% (Fig. 3). Based on this result, we set the removal depth of the machine to 5 cm and proceeded with operation. Tables 3 and 4 list the effects of removal.

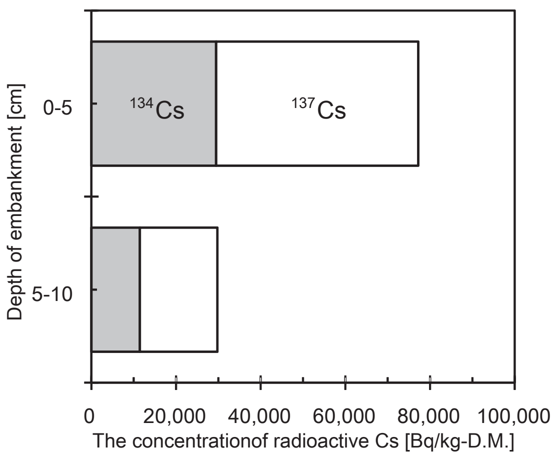


Fig. 3. Vertical distribution proportion of radioactive Cs in soil on an embankment

The concentration of radioactive Cs was 77,212 Bq/kg in dry soil prior to treatment. After the treatment, the concentration in the first layer of topsoil at a depth of 5 cm was reduced by about 78% to 16,371 Bq/kg. This roughly matches the vertical distribution ratio of radioactive Cs in the soil mentioned above. Between the two isotopes of radioactive Cs, the proportion of ^{137}Cs was around 62% both before and after treatment. The ambient

Table 3. The effects of reduced radioactive Cs in embankment topsoil

Concentration of radioactive Cs (Bq/kg-D.M.)						Rate of reduction (%)
Before treatment			After treatment			
^{134}Cs	^{137}Cs	Total	^{134}Cs	^{137}Cs	total	
29,458	47,754	77,212	6,293	10,078	16,371	78.8

Note 1) Analysis conducted with a germanium semiconductor detector unit (outsourced to Hitachi Kyowa Engineering)
Note 2) Sample before treatment on March 11, 2012; after treatment on March 15, 2012
Soil samples before and after treatment were taken from the first 0-5 cm of topsoil.

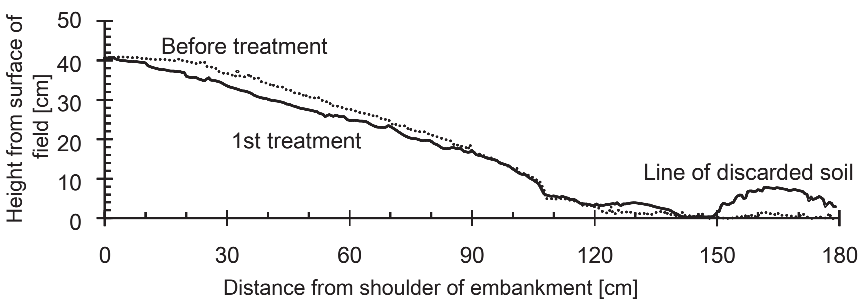


Fig. 4. Surface profile of an embankment before and after treatment

Table 4. The effects of reduced ambient dose rate at 1 cm above the embankment surface

Ambient dose rate (μSv/h)			Rate of reduction (%)	
Before treatment	Immediately after treatment	42 days after	Immediately after treatment	42 days after
1.37±0.24	0.27±0.08	0.22±0.02	80.3±2.0	83.7±2.7

Note 1) Using collimator method
Note 2) Measurement before treatment on March 14, 2012; immediately after treatment on March 15, 2012

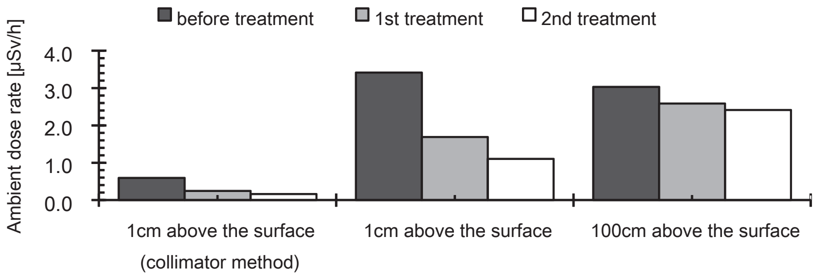


Fig. 5. Ambient dose rate at 1 cm (collimator method) and 100 cm above the embankment surface before and after treatment

dose rate at 1 cm above the surface was reduced by about 80% (from 1.37 µSv/h before treatment to 0.27 µSv/h after treatment), thereby confirming roughly equivalent decontamination effects.

In the field testing conducted in June 2012, we attempted to reduce the amount of soil removed as much as possible by removing it carefully at a shallower depth. We conducted a continuous operation with the removal depth set to 3 cm. We worked on an embankment (as shown in Fig. 4) at an operating speed of 0.08 m/s and achieved a field capacity of 4.4 a/h.

The line of discarded soil formed at the base of the embankment was approximately 30-cm wide and linear shaped (Fig. 4). The amount of discarded soil was approximately 3.0 t/a, or about three bags/a using 1 m^3-sized flexible container bags. As shown in the figure, the entire surface could not be evenly removed due to surface inequalities, however, and overall it proved to be a somewhat shallow surface removal of 2.5 ± 1.8 cm (mean ± std.). As a result, the ambient dose rate at 1 cm above the surface (collimator method) was only reduced by 59% from 0.60 ± 0.09 µSv/h before treatment to 0.24 ± 0.05 µSv/h after treatment. Repeating the treatment under the same machine conditions and focusing mainly on the lower section of the embankment resulted in a reading of 0.16 ± 0.03 µSv/h—a reduction of 73% compared with the reading before treatment (Fig. 5).

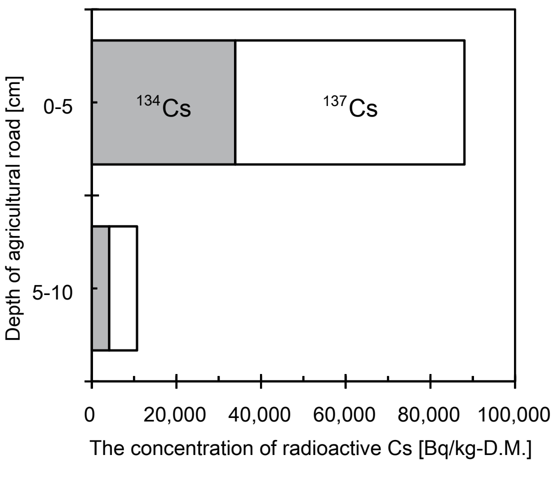


Fig. 6. Vertical distribution proportion of radioactive Cs in soil on an agricultural road

(2) Usability and decontamination effects of the agricultural road surface stripping machine

The test tractor was a 77.2 kW half-track model (EG105 made by Yanmar Co., Ltd.). To ascertain the contamination status of the testing site, an agricultural road at the side of a field (in the Itamizawa district of Iitate village), we sampled soil at a depth of 10 cm at 5-cm intervals, and then measured the vertical distribution of radioactive Cs concentration in the soil. The analysis results of this sampling revealed that the ratio of radioactive Cs (^{134}Cs and ^{137}Cs) deposited in the first 0-5 cm of topsoil was about 90% (Fig. 6). Compared with the embankment of the previous subsection, where the deposition ratio of radioactive Cs in the first 0-5 cm of topsoil was about 70%, we confirmed that a relatively larger portion of cesium had accumulated in the agricultural road surface. Moreover, as with the embankment, the ratio of ^{137}Cs between the two radioactive Cs types was 62%, regardless of depth. Fig. 7 shows the decontamination

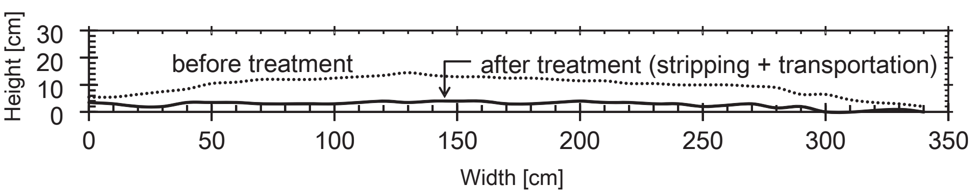


Fig. 7. Surface profile of an agricultural road before and after treatment

Table 5. The effects of removing radioactive Cs in agricultural road

Measuring point	Concentration of radioactive Cs (Bq/kg-D.M.)						Rate of reduction (%)
	Before treatment			After treatment			
	^{134}Cs	^{137}Cs	total	^{134}Cs	^{137}Cs	total	
Right shoulder	65,758	104,808	170,566	2,361	3,858	6,219	96.4
Right wheel track	6,123	9,859	15,982	149	206	355	97.8
Center	13,114	21,064	34,178	157	255	411	98.8
Left wheel track	12,574	20,345	32,919	118	192	311	99.1
Left shoulder	71,800	114,799	186,599	3,940	6,244	10,185	94.5
Ave.	33,874	54,175	88,049	1,345	2,151	3,496	97.3

Note 1) All soil samples were taken from the first 0-5 cm of topsoil. Analysis was conducted with a germanium semiconductor detector.
Note 2) Sample prior to treatment on March 11, 2012; after treatment on March 15, 2012

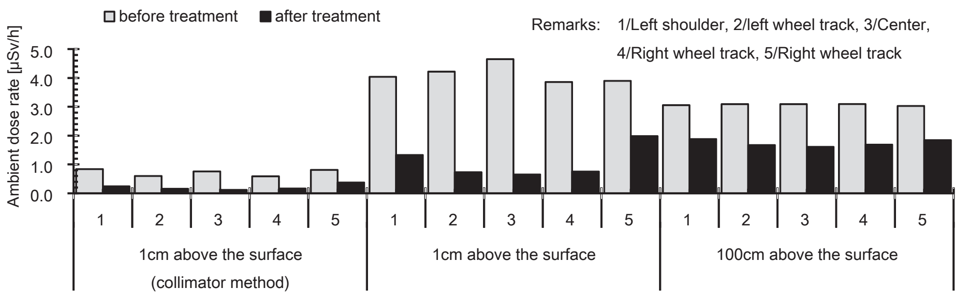


Fig. 8. Ambient dose rates above the agricultural road surface before and after treatment
(Test conducted at Yawaki, Iitoi, and Iitate village in June 2012)

operation using the machine, and the agricultural road surface profile before and after treatment. Table 5 lists the decontamination effects.

The machine was used to perform stripping operations on two testing areas at a speed of between 0.11 and 0.13 m/s. Note that a return trip operation is required for an agricultural road with a width of 3.4 m. A 100-m stretch of road can be treated in about 30-35 minutes. However, in the system for decontamination operation, the concentration of radioactive material is not reduced until all the stripped contaminated soil is collected and removed. In this system, we used a front loader to collect all the stripped contaminated soil and load it onto a truck. Based on the test results, the field capacity was approximately 0.83 a/h. The stripping operation accounted for 16% of this time, while the collection and transportation of soil accounted for 84%.

As shown in Fig. 7, while certain deviations exist due to surface inequalities in different parts of the agricultural road, the overall removal depth was 5.9 ± 2.8 cm (mean ± standard deviation). Moreover, sifting analysis of the crushed soil confirmed that the soil was mostly comprised of gravel smaller than medium size, with coarse gravel (19.0-26.5 mm) accounting for 11%, medium gravel (2.0-19.0 mm) for 57%, and fine gravel (2.0 mm and below) for 32% of the volume. Because the road was an agricultural road, it only contained relatively small stones, so that a good crushed soil was obtainable even if the rear cover of the operating section was left somewhat open (the condition for a large crushing diameter) during operation.

In the field test conducted in March 2012 (Table 5), the concentration of radioactive Cs in the first 0-5 cm of topsoil was 88,049 Bq/kg in dry soil before treatment and 3,496 Bq/kg after the soil stripping and removal treatment, for an extremely high reduction rate of 97%. Moreover, we observed that the decontamination effect on the shoulders of the road tended to be somewhat lower than that at the center of the road. The difference is attributed to a shallower removal depth along the shoulders and a greater incline than at the center. The ambient dose rate at 1 cm above the surface (collimator method) decreased by approximately 85% from 1.38 μSv/h before treatment to 0.20 μSv/h after treatment for a

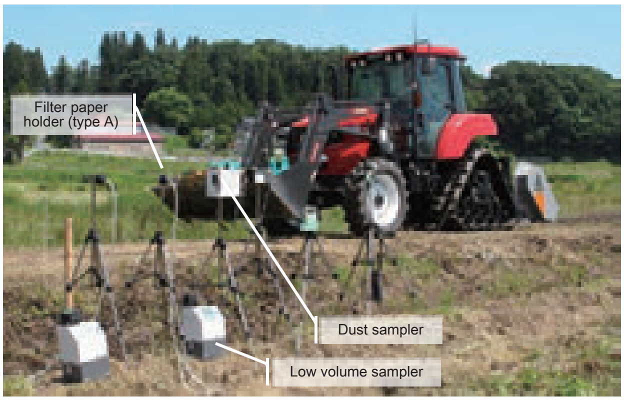


Fig. 9. Testing and measuring dust exposure status during decontamination operation

powerful decontamination effect. One and a half months after treatment, the rate was confirmed as being about the same as directly after treatment at 0.21 μSv/h. Fig. 8 shows the decontamination effects from the test conducted at Yawaki, Iitoi, and Iitatemura in June 2012.

The ambient dose rates before treatment at 1 cm above the surface (collimator method), 1 cm, and 100 cm above the surface were 0.72 ± 0.12 μSv/h, 4.13 ± 0.23 μSv/h, and 3.08 ± 0.09 μSv/h, respectively. After the stripping and removal treatment, the rates were 0.21 ± 0.10 μSv/h, 1.09 ± 0.32 μSv/h, and 1.74 ± 0.15 μSv/h (representing reduction rates of 71%, 73%, and 43%), respectively. We therefore achieved a relatively powerful reduction effect from a single stripping operation. And as indicated by the results of the test conducted in March as described above, the decontamination effect tended to be somewhat lower along the shoulders of the road as compared with that at the center. The reason for this difference is considered to be the same as described above.

(3) Status of dust exposure during decontamination operation

During the decontamination operation, information necessary for exposure management must be presented in order to prevent harm from radiation, establish an efficient operation system, and provide safer systemization technologies. To confirm the efficacy of technologies for controlling and reducing the amount of radiation exposure experienced by the operators of our developed machinery, we surveyed the dust exposure status as an operating environment factor related to worker safety (Fig. 9). Because our developed machines use a tractor as the main operating machine, we measured the dust concentration near the mouth of an operator sitting inside the tractor's cabin, and in the environment around the work site.

Under the Ionizing Radiation Ordinance for Decontamination, the target particle diameter for measuring dust concentrations in the workplace environment is that of inhalable particles (100 μm, 50% cut), which could enter the nose or mouth from nearby air and cause internal exposure (Ministry of Health, Labour and Welfare Office for Measures to Protect Workers' Health from Ionizing Radiation, 2012). This is different from the particle diameter of inhalable dust thought to affect human lungs (PM4: 4 μm, 50% cut), as stipulated under Article 2-2 of the Standards for Working Environment Measurement. This is because particles of such size that may lodge in the upper section of ciliated airways are considered highly likely to migrate to the digestive tract.

The dust concentration inside the tractor cabin during decontamination work along the periphery of agricultural land was 0.23 mg/m^3 when decontaminating the embankment and 0.47 mg/m^3 when decontaminating the agricultural road. At a point approximately 5 m distant from the work site, the concentration was 0.23 mg/m^3 when decontaminating the embankment and 0.98 mg/m^3 when decontaminating the agricultural road (Table 6). These concentration levels are all significantly lower than the high concentration level of 10 mg/m^3 recognized under the Ionizing Radiation Ordinance for Decontamination. Without making an unconditional statement, the fully enclosed construction of the operating section of both machines apparently contributes to preventing exposure to the operator and the surrounding environment.

Table 6. Dust concentrations inside the tractor cabin and surrounding environment during decontamination operation

	Relative dust concentration (cpm)		Conversion dust concentration (mg/m^3)		Soil and weather conditions	
	Inside tractor cabin	Surrounding environment	Inside tractor cabin	Surrounding environment	Moisture ratio (%)	Wind velocity (m/s)
Embankment	7.6	7.7	0.23	0.23	28.5	1.7
Agricultural road	15.7	32.5	0.47	0.98	21.2	1.9

Remarks) Conversion dust concentration (mg/m^3) = concentration conversion coefficient based on mass (K-value, mg/m^3/cpm)×Relative dust concentration (cpm), Set K-value with 0.03

Fig. 10. Modified type of embankment topsoil removal machine

Fig. 11. Treated surface and rows of discarded soil after reciprocating removal work using modified type of embankment topsoil removal machine

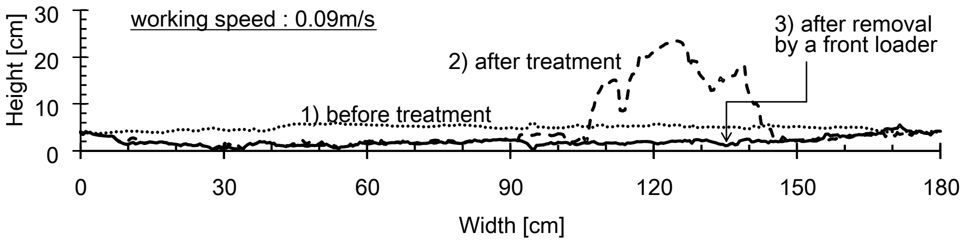


Fig. 12. Surface profile by operation to remove topsoil from a rice paddy using modified type of embankment topsoil removal machine

4. Extending applicability of the developed machines

During field testing of the embankment topsoil removal machine for removing a thin surface layer of topsoil, local farmers and others expressed a desire to apply the decontamination technology not only to the periphery of agricultural land but also to the agricultural land itself. In response, we modified part of the mechanism for discarding soil of the aforementioned embankment topsoil removal machine, and then tested it in an operation to remove topsoil from a rice paddy. For the modification, based on the premise of removing topsoil from a level site, we fixed a 1.5-m-wide blade diagonally to the machine so that soil discarded from the outlet on the left edge of the section for conveying discarded soil would form a row of discarded soil, while being discarded and piled up toward the rearward side.

As a result of continuous operation with the removal depth set at 3 cm and working at a speed of 0.09 m/s (as shown in Fig. 10 and 11), the machine achieved mostly uniform operational accuracy in removing a thin layer with a removal depth of 2.9 ± 1.4 cm. A row of discarded soil was formed behind the machine at about 30 cm in from the left edge, and a field capacity of 4.9 a/h was achieved. The volume of removed soil was calculated at approximately 30 t/10 a, and estimated to fill about 30 1-m^3 flexible container bags per 10 a. From the topsoil profile before and after treatment (as shown in Fig. 12), it was confirmed that the treated surface was flat overall, and that the discarded soil formed a row approximately 40 cm in width and 20 cm in height, which could be easily collected by a front loader in a subsequent operation. We also tested the machine in lowland fields within the area of decontamination, and found significant improvement of the machine. Thus, the machine proved to be efficient and offering practical use. As a result, this machine will be marketed and used in Fukushima to decontaminate agricultural land in 2015.

Conclusion

The Act on Special Measures Concerning the Handling of Radioactive Pollution recommends measures to be taken by the national government, local governments, and relevant nuclear power operators to counteract contamination caused by the fallout of radioactive material following a nuclear power plant accident. The Act was fully enforced from January 1, 2012, with the aim of quickly reducing the impact of environmental contamination on human health and living environments. Under the Act, the areas for which the national government is responsible for decontaminating, such as areas on high alert or areas subject to planned evacuation, are designated as Special Decontamination Areas, while cities, towns, and villages containing areas where the ambient dose rate exceeds 0.23 μSv/h are designated as Intensive Contamination Survey Areas. The national government has been working to formulate decontamination plans for these areas (National Institute for Agro-Environmental Sciences, 2012; Ministry of the Environment, 2012). Assuming that decontamination operations will be undertaken in agricultural production areas, the previously mentioned machine technologies based on tractors can be provided as a means of agricultural management or an extension thereof. Looking ahead, we plan to continue working closely with local governments, corporations, relevant organizations, and research institutions to verify and promote these technologies, while working to increase countermeasures for radioactive material.

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