Annex 4 Explanation of each technology

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1. Basic findings on contamination of agricultural soil

1) 95 percent of radiocesium (a total of ^{134}Cs and ^{137}Cs) exists in unplowed soil down to 2.5cm depth from the surface (Figure 1)

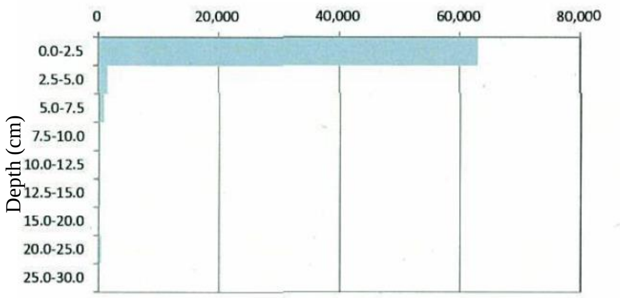

Figure 1 Radiocesium concentrations in the paddy fields at Itamizawa, Iitate Village

2) Radiocesium strongly binds with clay particles, etc. in agricultural soil and does not elute into water easily (Table 1). The contamination in water such as held in reservoirs and irrigation water supplies is minimal (Table 2).

Table 1 Extraction test of radiocesium (^{134}Cs plus ^{137}Cs) in the agricultural soil of Fukushima Prefecture

Types of soil	Extraction with water	Extraction with ammonium acetate
Soil in paddy fields	ND	2.3%
Soil in crop fields	ND	5.3%

Note: Detection limit (0.4 Bq/L)

Table 2 Measurement of radiocesium concentrations (^{134}Cs plus ^{137}Cs) in the water around the paddy fields for the demonstration test at Iitate Village

Types of water	Concentration of radioactive materials
Reservoir (Source) water	ND
Nearby Nitagawa river water	ND
Groundwater of an observation well	ND
Water for plowing	ND

Note: Detection limit (4-7 Bq/L)

3) A lot of radiocesium binds with fine soil particles such as clay and silt. (Table 3)

Table 3 Measurement results of radiocesium concentration by particle size in the soil layers for preliminary sampling (0-2.5 cm depth, at Itamizawa)

Depth of the soil	Classifications of particle size by the International Society of Soil Science		Composition (%)	Bq/kg (each composition)	Bq/overall sample	Bq ratio (%)
0-2.5cm	Clay	Up to 2μm	4.8	174,300	8,4000	13
	Silt	20-2μm	29.6	103,300	30,600	46.4
	Fine sand	200-20μm	45.2	48,000	21,700	32.9
	Coarse sand	2mm-200μm	20.4	25,900	5,280	8.0

Note: The radioactivity concentration of the overall topsoil layer of 0-2.5cm in depth is 65,923 Bq/kg. The soil sample was collected in June 2011.

2. Scraping the topsoil

2-1) Basic scraping of the topsoil

1. Overview

Radioactive materials that deposited onto agricultural soil are concentrated in the surface layer of the soil. Therefore, it is considered that contaminated agricultural soil can be restored to usable conditions by removing the soil of the surface layer retaining the radioactive materials. A test was conducted with the purpose of developing technologies to physically remove the topsoil of agricultural land.

○ Responsible organization: Agricultural Research Center of the National Agriculture and Food Research Organization (NARO)

○ Demonstration test field: a paddy field (8 a) at Iitoi, Iitate Village, Soma County, Fukushima Prefecture

2. Procedures of the work

The work was conducted in the order of breaking, scraping, removing and then bagging the soil.

1) Breaking soil: A vertical harrows attachment was fitted to an agricultural tractor, and was used to break the agricultural topsoil shallowly (4-5 cm in depth) and soften it.
2) Scraping: A rear blade was fitted to the tractor to scrape off the broken topsoil in 5-10 m legs in the direction towards the field shortest-side to collect the soil.

3) Removal of soil for disposal/bagging: The collected soil was loaded onto a truck using the front loader of the tractor and transported from the agricultural field. The agricultural soil was put into sandbags using a backhoe and other devices.


Photos 1: Breaking soil


Photos 2: Scraping and collecting soil


Photos 3: Disposal of soil

3. Overview of results and discussions (see Tables 1 and 2)

1) Radiocesium concentration in the soil was reduced from 10,370 Bq/kg to 2,599 Bq/kg by scraping the topsoil of the paddy field down to 4 cm (approx. 40 m^3/10 a). The ambient dose rate above the topsoil decreased from 7.14 μSv/h to 3.39 μSv/h after removing the topsoil. The time to the completion of scraping was 55-70 min/10 a.
2) The most time consuming task was removing the scraped soil from the field and putting it into bags. It is particularly important to have a more efficient way of transporting the soil removed from the field.
3) The amount of time required for the work depends on the conditions of the agricultural field, the skill levels of the operators and the distance the soil is transported, etc.
4) Measures should be taken in order to protect workers from internal exposure by soil dust and other dust generated during the work.
5) For agricultural land with high radiation exposure doses, it is necessary to consider scraping off a thicker surface layer to ensure that the radioactivity concentration of the soil for disposal does not exceed 100,000 Bq/kg.

Table 1: Radiocesium concentrations in soil (unit - Bq/kg, the soil layer - 15 cm)

	Pre-scraping	Post-scraping	Removed soil	Reduction rate (%)
Paddy field	10,370	2,599	44,253	75

Table 2: Duration by type of work (per 10 a)

Type of work	Duration	No. of workers	Machines required
Breaking	15-20 min	1	Tractor, vertical harrows attachment
Scraping	40-50min	1	Tractor, rear blade scraper
Collecting and removing	70-85 min	2 (One each for tractor and truck driving)	tractor, front-loader
Bagging	15-20min	2 (One for the backhoe and one for assistance)	Backhoe, stands for large and standard sized sand bags

*When there is grass on the agricultural field, weeding work will be required which is not included in the times given.

4. Planning and tasks for the future

1) Survey of radiocesium content of rice harvested from paddy fields

2-2) Scraping the topsoil using fixation agents

1. Overview

The surface layer of the soil was scraped after the soil was solidified by spraying fixation agents with the main material being either magnesium oxide or polyions onto the surface of the agricultural soil. This test was aimed at developing technologies to scrape off the surface layer of the soil where much of the radiocesium is contained and effectively remove contaminated soil.

- ○ Responsible organizations: the National Institute for Rural Engineering of NARO; the Japan Atomic Energy Agency (JAEA)
- ○ Demonstration test field: Local agricultural field in the Itamizawa area of Iitate Village, Soma County, Fukushima Prefecture (10 a)

2. Procedures of the work (in the case of using magnesium fixation agent)

1) A solution with the magnesium oxide fixation agent mixed with water was sprayed onto the agricultural field
2) The surface layer of the soil was scraped once the fixation agent had penetrated into the soil and full solidification of the soil was confirmed (after 7-10 days under good weather conditions). Scraping was performed by pushing and swinging the arm of a hydraulic shovel. In this way, even thickness of the scraped soil can be obtained. The improvement of using the bucket attachment on the arm makes the collection of soil for disposal by a truck equipped with a vacuum hose possible and no soil for disposal remains on the agricultural field.
3) Removed soil which was collected by a truck with a vacuum hose was transferred to flexible container bags and temporarily stored at a designated place.

Photo 1: Spraying the fixation agent

Photo 2: Agricultural field after application of fixation agent

3. Overview of the results and discussion (see Table 1)

1) Radiocesium concentration in the soil was reduced from 9,090 Bq/kg to 1,671 Bq/kg by scraping off the topsoil layer of the agricultural field. The radiation exposure dose rate above the

topsoil in the agricultural field decreased from 7.76 μSv/h to 3.57 μSv/h after removing the topsoil.

2) The amount of soil for disposal was 30 m^3 per 10a. The thickness of the layer scraped off was estimated to be around 3.0 cm.
3) The procedure improvement to use the bucket of a hydraulic shovel allowed three works steps (scraping/collecting/transporting) to be combined into one step.
4) By solidifying the surface layer of the soil, suppression of the spread of soil can be expected to be achieved.
5) The topsoil was marked white by spraying it with a fixation agent allowing visual checking of un-scraped areas.
6) Fixation agents can be applied even to paddy fields including areas with rice stubble and uneven soil.
7) When the topsoil is wet after rain, the mixed solution of solidifier may not penetrate to the required depth. Therefore, it is advisable that the fixation agent is sprayed when the agricultural field is dry.
8) It is necessary to remove weeds in the agricultural field prior to spraying the mixed solution.
9) The same effect can be expected using polyions and molecular polymers (a preliminary test was conducted at Iitate Village by JAEA).

Photo 3: Scraping the surface of the soil   Photo 4: Using the improved bucket

Table 1: Overview of the results

	Radiocesium concentrations (Bq/kg, dry soil)	Reduction rates (%)	Radiation dose rates on the surface area (μSv/h)
Pre-scraping	9,090	-	7.76
Post-scraping	1,671	82	3.57

4. Planning and tasks for the future

1) Improvements of the bucket to efficiently suck up the scraped topsoil
2) Review other efficient methods of collecting scraped topsoil other than the sucking up the scraped topsoil.

Photo 5: Solidified soil using polyions

2-3) Uprooting and removing grass/pasture

1. Overview

Efficiently removing the contaminated soil together with the surface grass and root mat was aimed for by utilizing a turf slicer, a machine for cutting strips of grass and root mat with attached soil.

○ Responsible organization: Fukushima Agricultural Technology Center

○ Demonstration test field:

1) Livestock Research Center, Numajiri Branch: Cutting grass and root mats using a turf slicer and collecting the grass, root mat and soil using a front loader
2) Pasture converted from paddy field at Iitoi, Iitate Village, Soma County, Fukushima Prefecture: Cutting grass and root mat using a turf slicer and collecting the grass, root mat and soil using a front loader

2. Procedures of the work

1) Cut grass and root mat using a turf slicer

2) Collecting and transporting away the grass, root mat and attached soil using a front loader

A turf slicer made by Sugano for agricultural purposes was used

The soil was taken off to 3 cm (rear strip) and 5 cm (front strip)

Short grass field

A front loader was used, the soil was scooped up and removed.

Long grass field

A front loader was used, the grass was torn up and removed.

3. Overview of results and discussions (see Table 1)

1) Cutting root mats layers with thicknesses of 3 cm and 5cm was possible using a turf slicer. The cutting speed was 0.15 km/h for both thicknesses.
2) Radiocesium concentration was reduced by 97% after cutting the root mat and attached soil to 3 cm thickness and 99% for 5 cm thickness. In both cases, the concentration was significantly

reduced.

3) It was confirmed that topsoil loss could be avoided from the root mats of pasture even with a grass height of 50 cm during the cutting of the grass by a turf slicer and tearing up and transporting the mats away using a front loader.
4) The duration of the work for the cutting of 3cm thickness was approximately 135 min/10 a and tearing up 113 min/10 a. The weight of the torn soil with grass was 41.6 tons.
5) At land converted from paddy field like the one at Iitate Village, the test site soil was thought to be torn deeper than expected when the soil was scooped up using a front loader. Therefore, the topsoil was torn off.
6) The work is easy for pasture where root mats are developed. However, it is more difficult for pasture without well-developed root mats.

Table 1: Radiocesium concentrations in the soil at the Iitate test site (unit: Bq/kg)

Samples (Depth of tearing)	Dry soil ^{134}Cs	Dry soil ^{137}Cs	Dry soil Cs total	Reduction rates (%)
Pre-uprooting and removing (mixed soil from 5 points)	6,394	7,236	13,630	-
5cm depth	80	97	177	98.5
3cm depth	147	180	327	97.2

Note: soil sample was taken from 15cm depth

4. Planning and tasks for the future

1) The effective usage of a turf slicer and front loader needs to be reviewed for land on a slope or with an uneven surface.
2) Methods to be applied for land where types of grass without root mats dominate, need to be reviewed.
3) A method for combining a sword grass cutter, a smaller type of the cutter and grass collection device is under review (at NARO)

3. Tilling/removing soil using water

1. Overview

After shallow tilling of the soil of the surface layer in paddy fields to mix it with water, the muddy water containing fine soil particles was drained off using a pump. At a sedimentation pond, the soil and water were separated and only the soil was disposed of. The aim of this method was to reduce the amount of soil for disposal and decontaminate the soil by taking out fine particles in the surface layer along with their high radiocesium concentration.

○ Responsible organizations: the National Institute for Rural Engineering of NARO; the National Institute for Agro-Environmental Sciences

○ Demonstration test field: Agricultural field, Iitate Village, Soma County, Fukushima Prefecture (4.2 a)

2. Procedures of the work

1) The surface layer was tilled down to a depth of about 2 cm using a vertical harrow.
2) Water was introduced into the paddy field and shallowly tilled to mix the soil and water.
3) The muddy water was forcefully drained into a sedimentation pond using a PVC pipe and a pump.
4) A coagulant agent was added, and the water and soil were separated at the sedimentation pond.
5) After determining the radioactivity concentration in the supernatant water, the water was drained off. The separated soil was dried and transferred into flexible containers and then stored temporarily at a designated place.

Photo 1: Mixing soil with water by shallow tilling

Photo 2: Draining muddy water into a sedimentation pond

3. Overview of the results and discussions

1) In a preliminary small scale test using a tractor attachment to mix the topsoil and water, the reduction rates of radiocesium in the soil varied depending on the types of soils. The rates were 29-71%. It was understood that in the soil with less clay component, high reduction rates could

not always be expected.

2) Radiocesium concentration in the soil was reduced from 15,254 Bq/kg to 9,689 Bq/kg by mixing soil (shallow tilling) and forcefully draining off the muddy water. The ambient dose rate above the agricultural topsoil was reduced from 7.55 μSv/h to 6.48 μSv/h.
3) From the preliminary test, the amount of soil for disposal was estimated to be 1.2-1.5 tons/10 a. The amount of soil for disposal in this method is expected to be one tenth compared with that generated by scraping off the topsoil layer.
4) Radiocesium concentration in the supernatant water after separating the soil from the water in the sedimentation pond was less than the detectable level. Therefore, the water can be returned to the environment.
5) When radioactive materials are dissolved into the water, passing through a water channel with a filter using Prussian blue non-woven fabrics (the Agency of Industrial Science and Technology) or absorption of the materials by natural minerals are possible removal options.
6) It is necessary to clear weeds on the agricultural field before tilling the soil.

Photo 3: Separation of solid-liquid at the sedimentation pond

Photo 4: Supernatant water after the solid-liquid separation (radiocesium concentration was less than the detectable level)

Table 1: Overview of the demonstration test results by tilling the surface of the soil

	Radiocesium concentration (Bq/kg, dry soil)	Reduction rate (%)	Radiation exposure dose rates above the topsoil
Pre-testing	15,254	-	7.55
Post-testing	9,689	36	6.48

4. Planning and tasks for the future

1) A demonstration test using a tractor attachment to mix the topsoil and water will be implemented in September (at the National Institute for Agro-Environmental Sciences), aiming at maintaining the muddy water condition and enhancing the decontamination efficiency.

4. Turning and plowing (inversion plowing)

1. Overview

This method aims to decrease the ambient dose rates above the topsoil and the transfer of radioactive materials to crops by turning and plowing in order to move the soil layer containing radiocesium contamination to a lower layer. The benefit of this inversion plowing is that there will be no soil for disposal. It is also expected that the cost of this method will be minimal. At this time, plowing at different depths was tested (30 cm, 45 cm and 60 cm down into the soil).

○ Responsible organizations: Agricultural Research Center of NARO (cooperating organization: the Bio-oriented Technology Research Advancement Institution)

○ Demonstration test field: A paddy field in Motomiya City, Fukushima Prefecture (28 a)

2. Procedures of the work

The procedures were in the order of 1) spraying an absorbent (i.e. vermiculite, etc.), 2) plowing, 3) stepping/breaking/smoothing the soil, 4) fertilizing, and 5) transferring.

Figure 1: A plow with a jointer attachment (30cm down into the soil, pulled by a tractor): Motomiya City, 9 May.

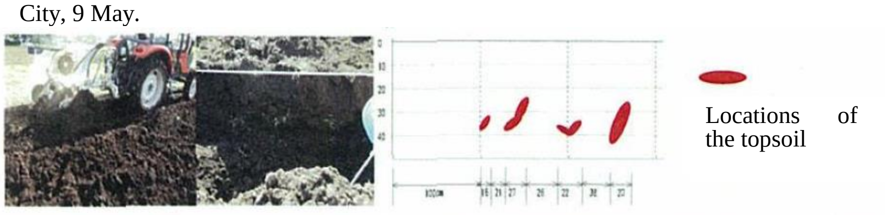

Figure 2: Modified two-step plow (deep plowing – 45 cm down into the soil, pulled by a tractor): NARO agricultural land, 29 August

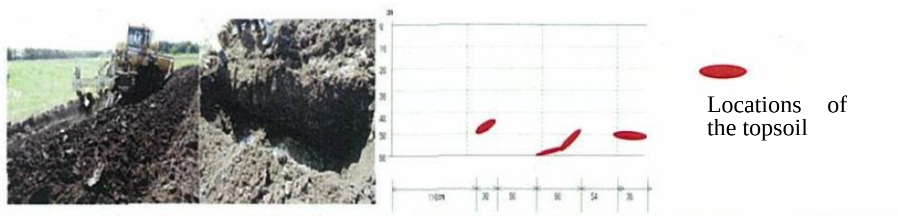

Figure 3: Modified two-step plow (deep plowing – 60 cm down into the soil, pulled by a tractor): NARO agricultural land, 29 August

3. Overview of the results and discussion

1) Radiocesium was transferred to the soil down to 15-20 cm depth by inversion plowing (30 cm)

in Motomiya City. The concentration level on the surface layer was apparently reduced (Figure 1).

2) The radiation exposure dose rates at the surface of the agricultural field were: 0.66 μSv/h (un-plowed), 0.40 μSv/h (plowed by a rotary machine) and 0.3 μSv/h (inversion plowing).
3) The work duration for inversion plowing was 0.5 h/10 a. After inversion plowing, rice seedlings were transferred to the paddy field without plowing. Rice was steadily growing at this stage.
4) By inversion plowing the soil down to 45 cm depth, the topsoil was transferred to the soil layer at the depth of 25-40 cm, and by plowing down to 60 cm depth, it was transferred to 40-60 cm depth.
5) Radioactive materials cannot be removed by this method. Therefore, it is a high risk to apply this method to highly contaminated agricultural fields. It should be applied to the soil where contamination is relatively low.
6) Prior to inversion plowing, it is necessary to evaluate the risks of contaminating groundwater by implementing a survey on the levels of groundwater and an elution test of radiocesium in the soil.
7) The deeper inversion plowing is applied, the higher the reduction effect is on the ambient dose rates above the topsoil. However, deep inversion plowing may destroy the hardpan. Inversion plowing of the soil down to 30 cm depth is suitable for paddy fields. However, paddy fields where the water reduction is high requires measures to prevent water leakage by plowing thoroughly.
8) When the quality of the soil in lower layers is poor, plants will have to be grown in the poor quality soil which was moved to the surface layer by inversion plowing. It is therefore necessary to implement measures to restore the fertility of the soil using fertilizers and/or materials to improve the soil.

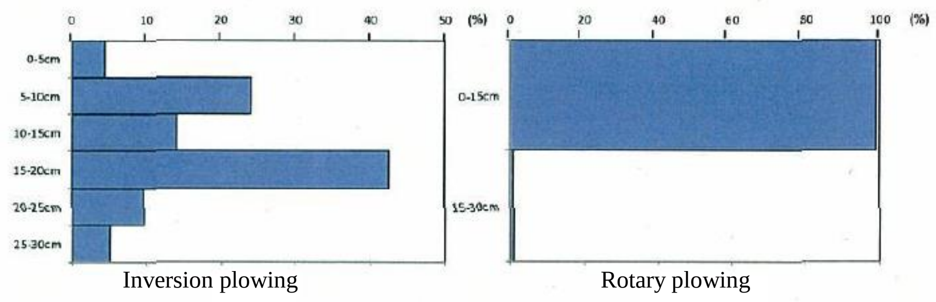

Figure 1: Depth profile of radiocesium after inversion plowing (30cm) in Motomiya City

4. Planning and tasks for the future

1) As soon as possible, a method for reviewing the risks of contaminating groundwater must be established prior to carrying out plowing on any large scale. 2) A survey on rice plants growing in the paddy field used for the demonstration test in Motomiya City will be conducted.

5. Decontamination using plants with high radioactive material absorption capability

1. Overview

This method is aimed at determining and verifying the effectiveness of technologies to collect radiocesium in the soil using plants which are thought to have high absorption capability for radiocesium (phytoremediation technology). Plants have been grown at the agricultural field of the research institute and also at an agricultural field in the area affected by the nuclear power accident. The absorption level of radioactive materials will be estimated and plant residue burning tests will be performed.

- ○ Responsible organizations: NARO Tohoku Agricultural Research Center; Fukushima Agricultural Technology Center; JAEA
- ○ Demonstration test field:
    1) Agricultural field at Nimaibashi, Iitate Village, Soma County, Fukushima Prefecture (15a): radiocesium concentration in the soil: 7,715 Bq/kg. Sunflowers (Asteraceae) and amaranth (Amaranthaceae) (sown on 28 May)
    2) Agricultural field at Yamakiya, Kawamata Town, Date County, Fukushima Prefecture (1a x 2): radiocesium concentration in the soil: 5,690 Bq/kg. Kenaf (Malvaceae), quinoa (Chenopodiaceae), and amaranth (Amaranthaceae) (sown on 29 June)

2. Procedures of the work

At the agricultural field in Nimaibashi District of Iitate Village (brown forest soil) and the agricultural field at Fukushima Agricultural Technology Center (grey upland soil), sunflowers and amaranth have been grown to determine the absorption rates of radiocesium.

At the agricultural field in Yamakiya District of Kawamata Town, kenaf, quinoa and amaranth have been grown to determine the absorption rates of radiocesium.

At the agricultural field of the National Agricultural Research Center for Tohoku Region, Fukushima Center (Andosol), in addition to two varieties of sunflowers, four varieties/families of amaranth, one variety each of quinoa and kenaf, one variety each of sorghum, millet and barnyard (all Gramineae) have been grown to compare the absorption rates of radiocesium.

Table 1 Test plan and flowering dates of sunflowers

Test field	Types of soil	Temperature in growing season	Seeding dates	Flowering dates
Iitate Village	Brown forest soil	20.0 °C	27 May	5 Aug.
Fukushima Center	Andosol	23.0 °C	25, 27 May	29, 31 Jul.

Fukushima Agricultural Technology Center	Grey upland sol	22.2 °C	17 May	20 Jul.

Note: Normal level of the average temperature from June to August.

3. Overview of the results and discussion (provisional)

1) The radiocesium concentration of sunflowers in the area with ammonium sulfate but without potassium at the agricultural field of Iitate Village on the flowering day (5 August) was 52 Bq/kg in the stems and leaves and 148 Bq/kg in the roots (Table 2). In this case, the transference rate of cesium from the soil (7,715 Bq/kg) to the stems and leaves was 0.00674.
2) Radiocesium in the soil of this agricultural field was calculated as 1,067,820 Bq/m^2. When the crop rate of sunflowers (fresh weight) was about 10kg/m^2 and the radiocesium concentration was 52Bq/kg, the cesium absorption into the sunflowers was determined as 520 Bq/m^2, which was about 1/2,000 of the radiocesium contained in the soil per square meter (1,067,820 Bq). From this result, the decontamination effect by sunflowers is considered to be minimal.
3) The level described above was achieved at the time the sunflowers were flowering. It will be necessary to have a comprehensive evaluation of samples collected during the period 30 days after flowering.

Table 2 Radiocesium concentrations in sunflowers at the time of flowering (Agricultural field at Nimaibashi, Iitate Village)

Parts	area	^{134}Cs Bq/kg, DW	^{137}Cs Bq/kg, DW	Total radiocesium Bq/kg, DW	Moisture content	Total radiocesium Bq/kg, FW
Stems and leaves	Ammonium sulfate without potassium	280	340	620	0.91	52
	Ammonium nitrate with potassium chloride	140	185	325	0.91	31

Average of 2 samples of stems and leaves in the two areas.

4. Planning and tasks for the future

The results for all plants tested have yet to be obtained and the suitability of other plants for this method cannot yet be determined. But as far as sunflowers are concerned, the absorption rate is low, and it takes an extremely long time for sunflowers to absorb radiocesium. Therefore, the sunflower option is not realistic.

Regarding sunflowers, they are harvested over time from the start of the flowering stage through 30 days after flowering and the radiocesium concentration is being sequentially measured over that period. A part of the sunflower harvest will be used for a combustion test to reduce the quantity of material without the spread of radioactive materials. Also other parts of the harvest will be examined, including the radiocesium concentration of the fully matured seeds, and the migration of radiocesium to sunflower oil will be surveyed.

For the other plants, after determining their stages of growth the amount of the harvests will be determined and the radiocesium concentrations will be sequentially measured.

Photo 1: Device for combustion tests

6. Intermediate treatment/management technologies of radioactive materials

6-1) Radiation shielding tests using concrete containers

1. Overview

This work aims at determining the radiation shielding effect by packing the flexible container bags containing removed soil (radiocesium concentration: about 50,000 Bq/kg) that was produced by the topsoil scraping test at Iitate Village on 13-15 June in concrete containers.

- ○ Responsible organizations: NARO National Institute for Rural Engineering and other organizations
- ○ Demonstration test fields: Iitoi, Iitate Village, Soma County, Fukushima Prefecture and other venues

2. Procedures of the work

The external size of the concrete containers used was 1.5m x 1.5m x 1.5m. The wall thickness was 15 cm. The internal volume was 1.6 m^3. The two types of concrete used consisted of normal concrete and high density concrete and each type of container weighed 4.2 tons and 6.0 tons respectively.

1) The concrete containers were positioned on the stable horizontal plane using a crane.
2) After the flexible bags containing the removed soil produced by the surface scraping test at Iitate Village were wrapped in waterproof sheets, the bags were placed in the concrete containers.
3) Insulating rubber hinges were used to hold the lid tightly on the body of each container, to prevent seepage of rainwater and leakage of the contents.

Photo 1: Positioning of a concrete container

Photo 2: Placing the flexible container bag in the concrete container.

3. Overview of the results and discussions

1) The radiation exposure dose rate at the surface of the concrete container with the soil bags in it was reduced by 90.1-94.3% compared with that of the flexible bags. The shielding effect from radiation of the concrete containers was confirmed (Table 1).
2) The place where the containers are located must be horizontal plane and the ground should be prepared so that it can support the total weight of the containers and bags.
3) When the concrete container is being lifted up by the crane, jigs should be used so that the suspension cables will not touch the container body. Also, sufficient space is required for turning the crane and outrigger.

Table 1: Radiation exposure dose rates at the surface of flexible container bags and concrete containers filled with soil bags

Measurement position	Types of containers	Distance from the surface	Dose rates (μSv/h)	Reduction rates (%)
Top	Flexible container bags	1 cm	3.31	-
		15 cm	2.92	11.8

	Normal concrete	1 cm	0.28	91.5
	Heavy concrete	1 cm	0.19	94.3
Bottom	Flexible bags	1 cm	3.85	-
		15 cm	3.31	14.0
	Normal concrete	1 cm	0.38	90.1
	Heavy concrete	1 cm	0.22	94.3

Note 1: The background influence was excluded by shielding the sensitive part of the dosimeter with a lead cylinder during the measurement.

Note 2: The radiation exposure dose rates at the surface of empty concrete containers: Normal concrete, 0.33 μSv/h; Heavy concrete, 0.20 μSv/h.

4. Planning and tasks for the future

1) A reduction in the weight of the concrete containers to make their handling easier and the change of characteristics of the containers according to the contamination concentrations of the soil need to be studied.
2) The radioactive soil generated by the demonstration tests needs to be removed from the test field (e.g. ways to transport the soil to the temporary storage area should be considered).

6-2) Developments of technologies to separate radioactive materials from the soil

1. Overview

The work is aimed at reducing the total amount of radioactive waste by recovering extracted radiocesium using Prussian blue nano particle absorption materials. Technologies to extract cesium in the soil into an aqueous solution with a low concentration acid were developed.

○ Responsible organization: The National Institute of Advanced Industrial Science and Technology (AIST)

2. Procedures of the work

Non-contaminated soil collected at a crop field at Iitate Village of Fukushima Prefecture, a planned evacuation area, was used (low layer soil, brown forest soil, containing 2.3±0.3 ppm of non-radioactive cesium).

1) Soil was washed with an aqueous solution containing a low concentration of acid and cesium ions were desorbed into the aqueous solution.
2) Cesium ions extracted were recovered with cesium absorbent, Prussian blue nano particles. Because the acid concentration of the aqueous solution was low, the solution could be reused for washing soil (left of Figure 1).
3) By connecting the above two processes, the continuous treatment of soil was possible (right of Figure 1).

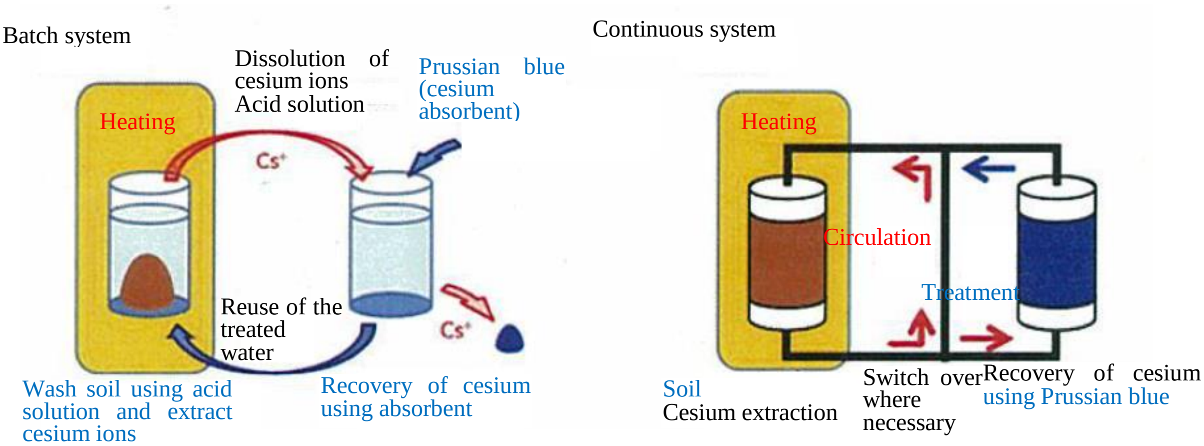

Figure 1: Extraction – recovery system of radiocesium from soil

3. Overview of the results and discussion

1) When using dilute nitric acid of 0.5 mol/L, extraction rates of cesium ions were improved by increasing the solid-liquid ratio (the weight of diluted nitric acid for soil) (Figure 2).

2) If radiocesium and non-radioactive cesium have similar chemical behaviors, almost 100% of the cesium ions can be recovered by increasing the level of the processing temperature to 200 °C in this method (Figure 3).
3) Cesium ions extracted from the soil were almost 100% recovered using Prussian blue nano particles. The volume of Prussian blue nano particles used for this test was 1/150 of the volume of the soil the cesium ions were extracted from.
4) The acid aqueous solution after recovering cesium ions could be reused simply by adjusting acid concentrations.
5) Non-radiocesium was used for the test. Radiocesium behavior needs to be tested before applying this method to practical use.
6) Because an acid aqueous solution is used, devices used for extraction need to be resistant to corrosion.
7) In order to heat the solution to 200 °C, pressurization is required.

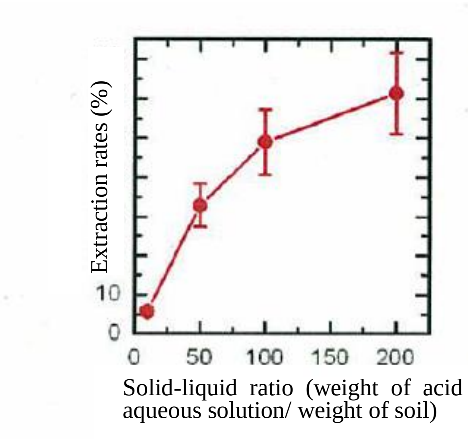

Figure 2: Changes of cesium extraction rates by solid-liquid ratios

The extraction rates of cesium ions at the time of mixing dilute nitric acid of 0.5 mol / L with soil, heating at 95 ℃, and letting it stand for 45 minutes.

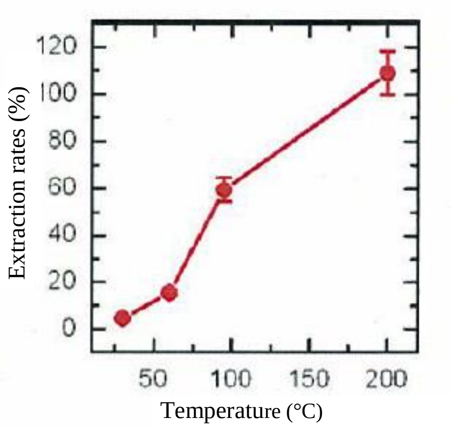

Figure 3: Changes of cesium extraction rates by temperature

Changes of cesium extraction rates when changing the temperature for extraction (nitric acid of 0.5mol/L, solid-liquid ratio of 200)
*The extraction rates exceeding 100% were caused by the uneven distribution of cesium ions in the soil.

4. Planning and tasks for the future

1) Improvement of the technologies including the optimization of temperatures for treatment and the concentration of acid in the solution, and the reduction of the weight of Prussian blue used for a given soil weight will be promoted.
2) Study will be continued on effects of acid on clay minerals of the soil after the treatment, etc.

6-3) Development of technologies to absorb/remove radioactive materials from aqueous solution

1. Overview

The work is aimed at evaluating different inorganic materials such as natural minerals as absorption materials for cesium dissolved in aqueous solution, and developing absorption materials with high cesium selectivity using chemical synthesis and molding technologies.

○ Responsible organizations: the National Institute for Material Science; JAEA; AIST

2. Methods of studies

1) Obtain basic data on cesium absorption characteristics of natural minerals (zeolite, smectite, vermiculite, iron minerals, carbide and layered double hydroxide) that are known to have selective absorption capability for cesium.
2) Develop various types of absorption materials suitable for application conditions using Prussian blue which is known for its cesium absorbability.
3) Evaluate cesium absorption capabilities and the method for mass production of the materials evaluated for a graft polymer which specifically absorbs cesium, and for crown ethers and proteins which are known as materials with high cesium absorbing capability. Field tests will also be conducted for these materials.

3. Overview of results and discussion

1) Tests were conducted using about 100 varieties of natural minerals at six levels of radiocesium concentration to determine equilibrium concentration, cesium absorption rates and distribution coefficient (Figure 1). The results obtained from the tests are being made open in the website of the material database of the National Institute for Materials Science (MatNavi) (Figure 2).

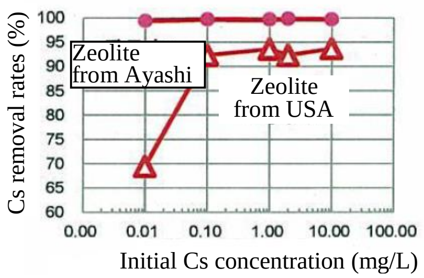

Figure 1: Example of cesium absorption test results

Figure 2: Material database site (http://mits.nims.go.jp/index_en.html)

2) Various types of absorption materials were developed using Prussian blue which absorbs cesium (Figure 3). A decontamination filter was developed to remove radiocesium from drained water

for the soil tilling and removal decontamination test by NARO (Figure 4). The filter demonstrated that water could be passed through the filter at a rate of 1.5 L/s.

Figure 3: Various types of absorption materials with Prussian blue

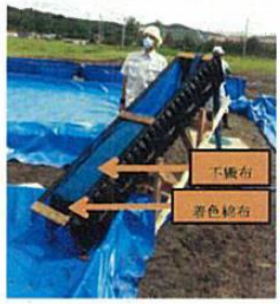

Figure 4: A demonstration test using a decontamination filter

3) A radiocesium absorption material using the graft polymer adsorbent can process large volumes of contaminated water about 3,000 times that of the material alone. This material can be mass produced at a cost of 10,000 yen/m^2. In a test performed on the reservoir water at Iitate Village, the radiocesium concentration of about 40 Bq/L was reduced to an undetectable level by combining the adsorbent with filtration of the water. (Figure 5)

4) A radiocesium selective crown ether was newly designed and developed. It was demonstrated that the cesium removal rate was nearly 100 %. Also, using a minimal amount of 0.1 N nitric solution, 100 % of cesium was recovered after removing from the adsorbent, indicating that the material can be used repeatedly (Figure 6). The production cost of this material is 15,000 yen/kg.

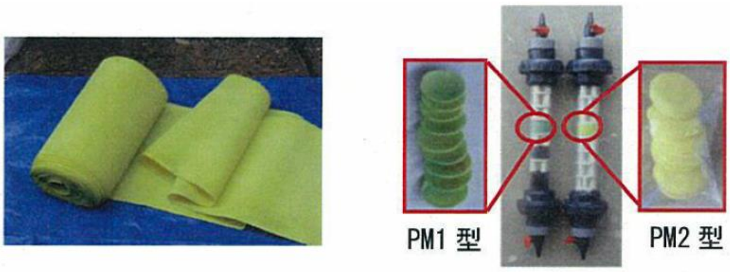

Figure 5: Mass production graft polymer adsorbent (left) and a radiocesium removal filtering device (right).

Figure 6: Cesium absorption structure by crown ether adsorbent (left) and a cesium removal device (middle photo, pre-filter; right photo, cyclone separator).

5) The technology is expected to be used for decontaminating water in various decontamination scenarios such as treatment of solutions where radiocesium was separated from soil.
6) Characteristics of natural minerals vary depending on manufacturers. There will be a need to review them prior to use.

4. Planning and tasks for the future

1) Absorption of cesium by protein materials was confirmed by artificially modifying the materials. However, mass production has not been established. Study on synthesis method of the materials will be required.