Report

Results of Removing Radioactive Cesium from the Shallow Rice Fields by Planting Sunflower
−Report from the Survey Team on the Absorption and Adsorption of Cesium by Planting Sunflower−

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A previous report presented successful examples of paddies and fields with a depth of over 20 cm being deep plowed to bring down external doses and thereby reduce the radioactivity levels in the soil (Bq/kg). This report presents the results of periodic measurements conducted to determine the level of absorption and adsorption of cesium by the roots and stems of sunflower plants during their growth in shallow paddies and fields. According to these measurements, sunflower plants absorbed and adsorbed the most cesium during their most vigorous period of growth immediately before their flowers bloomed.

I. Choosing the Appropriate Approach according to the Degree of Contamination

The Hamadori region of Fukushima Prefecture extends from the Pacific coast and across the Abukuma Highlands and other mountains that begin to loom around 10 km inland. Roads have been built alongside the narrow mountain streams that meander through the highlands, with forests and hills towering over them. After the accident that occurred at the Fukushima Daiichi Nuclear Power Plant in March 2011, air carrying a high concentration of radioactivity is thought to have spread across the Hamadori plain and advanced through the exposed valleys in the highlands, contaminating the roads along the way. The nuclear power plant is located in the town of Futaba. In the north, Prefectural Road 114 runs from Namie Town along the Ukedo River, which is famed for its salmon runs. Approximately 30 km further west-northwest along this road (commonly known as the Tomioka Kaido), there is an intersection with Prefectural Road 399 from Katsurao Village.

Road 114 runs through rugged terrain, while Road 399 runs along land at a lower elevation. The heavily contaminated air is believed to have advanced north along Road 399. Further to the north, Iitate Village is located on a low-lying alluvial fan. The heavily contaminated air first spread over Iitate Village before extending into Kawamata Town and Ryozen with a

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slightly lower radioactivity concentration. Highly contaminated areas extended into the districts of Murohara, Kawabusa, Hirusone, Kunugidaira, and Akougi in Namie Town along Road 114, as well as Naganuma in Iitate Village along Road 399. In other words, the number of highly contaminated areas is limited. An effective decontamination method involves scraping off a few centimeters or more of the topsoil and transporting it to final disposal sites after interim storage.

However, there are downsides to performing this topsoil scraping in all of the contaminated areas rather than only in highly contaminated areas. Not to mention the problems associated with establishing sites for the interim storage facilities (i.e., the difficulty involved in gaining consent from neighboring districts and local governments), the removal of topsoil removes nutrients from the soil and more than 10 years would be required to restore them. A long-lasting decline in agriculture is just one of the many problems that would be caused by topsoil removal.

II. Decontamination of Deep Paddies and Fields in Slightly or Moderately Contaminated Areas

As mentioned in a previous report [1)], the primary industry in the affected areas is agriculture, so its restoration is vital. In paddies and fields with a depth of over 20 cm, deep plowing reduces the external dose rate (μSv/h) to between one-third and one-fifth owing to the shielding effect of the soil. The average dose rate in ground that has a high cesium concentration in its top few centimeters can be reduced to between one-fifth and one-tenth (Bq/kg) [2)] by even plowing to a depth of 20 cm.

As an experiment, the author’s father grew Irish potatoes and sweet potatoes after plowing his plot in Minamisoma City. According to the measurements collected by a public agency, crops with relatively high transfer factors had a cesium concentration that was below the detection limit of 7 Bq/kg. The author has informed stakeholders in Minamisoma City of this method. The method has been put into practice in the Ota District of Hara Town Ward and the Jisabara District of Kashima Ward in Minamisoma City.

III. Decontamination of Shallow Paddies and Fields with a Depth of No More Than 15 cm by Soil Dressing

Many paddies and fields have a depth of no more than 15 cm, such as paddies with soil that has been improved so that they can be irrigated using less river water. These paddies and fields are not deep enough for the cesium to be diluted by tilling the soil. One possible alternative method would be to dress or cover them with clean soil, but 4.5 t trucks would have to transport 60 loads just to add a 20 cm layer of soil to a paddy with an area of 1,000 m^2. Furthermore, preparing the clean soil required to cover many paddies would not be easy. The amount of soil to be transported by trucks would be overwhelming. In addition, the mountain soil that would need to be used to dress the paddies contains fewer nutrients, so it would take more than 10 years to prepare the soil.

IV. Decontamination of Shallow Paddies and Fields with a Depth of No More Than 15 cm by the Selective Removal of Cesium

Various methods can be used for the selective removal of cesium. One possible method is chemical adsorption, but a great deal of effort and energy would be required to introduce the surface soil into a machine, treat it with chemicals, return the treated topsoil to the ground, and then properly clean up the used chemicals.

Another possible method involves the use of plants. Sunflower plants were used extensively in decontaminating areas affected by the Chernobyl nuclear disaster that occurred in 1986. The effectiveness of this method was also assessed in Japan when the Ministry of Agriculture, Forestry and Fisheries (MAFF) planted sunflowers in various areas affected by the nuclear accident that struck in 2011. The results, which were also published online [3)], were as follows: "Sunflower plants were grown in two fields in Koriyama City and Iitate Village, Fukushima Prefecture. The level of radioactive cesium in the soil measured 1,045 Bq/kg in Koriyama City and 7,715 Bq/kg in Iitate Village. The radioactive cesium concentration (fresh forage weight) was measured using 10 samples of aboveground portions and four root samples that were taken from the moment sunflowers began to bloom until 20 days later. The former samples (stems and flowers) measured between 12 and 79 Bq/kg, while the roots measured between 64 and 232 Bq/kg." The results of this experiment by the MAFF suggest that using sunflower plants to remove cesium is inefficient, and the MAFF seems to have completely abandoned the idea.

V. Investigation on Decontamination Using Sunflower Plants

Sunflower cultivation is the only realistic option for decontaminating shallow paddies and fields. Risking failure, the author asked his collaborators in the Ota District of Hara Town Ward and the Jisabara District of Kashima Ward in Minamisoma City to try growing sunflowers. In the investigation, the feasibility of decontamination using sunflowers and the optimal method for doing so were explored. To this end, members of the local community were asked to carry out the following four tasks: (1) till their fields before growing the sunflowers to distribute the cesium concentration evenly at all depths; (2) periodically measure the cesium concentration along with the growth of the sunflowers; (3) weigh the respective parts of the sunflower plants; and (4) measure the cesium concentration at all depths.

VI. Measurement Method Employed on Site

The author consulted Mr. Hideo Kobayashi of the Japan Atomic Energy Agency (JAEA) to choose a method for performing the on-site measurements. Based on the outcome of this consultation, samples of the soil were placed in Tupperware containers of the same shape (diameter: 90 mm; depth: 55 mm). The soil was then dried and made even after any stones had been removed. With local support from Minamisoma City and other organizations, the soil samples were prepared for the quantitative analysis of Cs-134, Cs-137 and K-40 using a germanium semiconductor detector and a multi-channel analyzer. The sampled soil was jointly prepared by Mr. Teruo Ara, from Minamisoma City, and the author based on the following three dose rate categories for standard samples: high (20,000 Bq/kg or more), medium (5,000 Bq/kg), and low (1,000 Bq/kg).

In Minamisoma City and other affected areas with a high dose rate, these standard samples with high, medium, and low dose rates were placed in a shielded container to eliminate any background radiation and other effects. After that, measurements were performed using the AP1000, an external dosimeter manufactured by Horiba. The total Cs-134 and Cs-137 radioactivity of the standard samples (high, medium, and low; expressed in Bq/kg) was presented along the vertical axis of a graph, while the net measurement obtained using an external dosimeter (excluding background radiation; expressed in μSv/h) was plotted along the horizontal axis. In this graph, dots corresponding to high, medium, and low were connected in a line to identify the correlation between the figures represented in Bq/kg and μSv/h.

At each site, the sampled soil was dried and placed in Tupperware containers of the same shape after any stones had been removed. After the samples had been weighed and measured in the shielded container, values in μSv/h were converted into Bq/kg (cesium) according to the correlation chart.

The cesium distribution according to the soil depth was examined using soil sampled from a level located 5 cm or 10 cm below the surface by using a scale and a planting trowel. Before any measurements were taken, the sampled roots and stems were washed in water, dried, crushed with a wooden hammer, and then pressed into Tupperware containers of the same shape. Even then, the weight of the sunflower roots was less than half that of the soil, which tended to cause errors. Despite this disadvantage, the method made it possible to take measurements on the spot, obtain the results immediately, and conduct additional surveys and consideration easily.

VII. Results from Measurements Taken of Soil and Sunflower Plants

The measurements taken demonstrate that a tiller can only mix soil down to 10 cm at most. A deep plow (overturning of the soil) can mix the soil down to 25 cm after repeated plowing. On July 28, 2012, residents from the Jisabara District were asked to bring the sunflowers that they had grown to a community hall. The author and other members of the team led by President Kumao Kaneko of the Japan Council on Energy & Security (Energy & Environment Email Forum) conducted an analysis of the sunflower roots, the sunflower stems, and the soil in which the sunflowers were grown. Twelve volunteers from Tokyo and other areas also assisted in the conducting of this analysis. This analysis was conducted immediately before the sunflowers flowered, and only one flower was spotted in a field containing many sunflower plants. **Table 1** shows the measurement results that were obtained. The first column indicates whether the samples were taken from the soil, roots, or stems. The second column lists the net measurements taken in the shielded container. The third column lists the corresponding values in Bq/kg based on the correlation chart. The fourth column lists the weight of each sample. The fifth column lists the ratio of the weight with respect to a standard sample. The last column (on the right) lists the derived measurements in Bq/kg after an adjustment for weight.

The sunflower roots recorded a cesium concentration of between 3,000 and 9,000 Bq/kg. The concentration in the sunflower stems ranged from a level below the detection limit to

Table 1 Cesium concentration in sunflower roots, sunflower stems, and the soil in which the sunflowers were grown

Sample		Net measurement	Converted using chart	Weight	Weight correction	Derived measurement
	Unit	μSv/h	Bq/kg	g		Bq/kg
A	Soil	0.064	3800	281	1.4	5320
	Roots	0.035	2300	103	3.82	8780
	Stem	ND	ND	265	1.48	ND
B	Soil	0.049	3000	290	1.36	4070
	Roots	0.067	4050	185	2.12	8600
	Stem	0.004	600	316	1.24	746
C	Soil	0.051	3250	479	0.82	2670
	Roots	0.125	7600	360	1.09	8300
	Stem	0.001	ND	123	3.2	ND
D	Soil	0.168	10155	463	0.85	8620
	Roots	0.038	2400	156	2.52	6050
	Stem	0.001	ND	191	2.06	ND
E	Soil	0.048	3000	435	0.9	2710
	Roots	0.024	2400	244	1.61	3870
	Stem	0.001	ND	236	1.67	ND
F	Soil	0.038	2450	391	1.01	2463
	Roots	0.040	2600	320	1.23	3193
	Stem	ND	ND	320	1.23	ND
G	Soil	0.112	6770	470	0.84	5660
	Roots	0.041	2600	381	1.03	2680
	Stem	0.004	600	284	1.38	830
H	Soil	0.049	3050	434	0.91	2760
	Roots	0.010	1000	149	2.64	2640
	Stem	0.013	1550	224	1.75	2720
I	Soil	0.057	3500	383	1.03	3591
	Roots	0.012	1100	185	2.12	2340
	Stem	0.015	1250	293	1.34	1667

somewhere around 1,000 Bq/kg. Both the roots and stems from sunflower plants that had been planted later and were still small recorded a concentration of around 2,000 Bq/kg. Measurements from the soil that was used to plant the sunflowers and measurements from the sunflower roots were weakly correlated.

On September 28 and 29, 2012, which was after the blooming season, the soil, roots, stems, and flowers of withered sunflowers with seeds were measured by Dr. Yasuhiko Fujii, Professor Emeritus of Tokyo Institute of Technology as well as 11 volunteers and the author. Cesium was not detected from most of the roots and stems.

VIII. Validation of Results

The results of measurements taken from the roots and stems of sunflowers in the Jisabara District on July 28 immediately before they bloomed differed considerably from the results of the measurements taken on September 28 after they had withered. Similarly, cesium was not detected in most measurements conducted on September 29 in the Ota District of Hara Town Ward. The aforementioned measurement method that was applied on the site has proven to be reliable, although it is associated with reasonable errors. These facts point to the near absence of cesium in the roots and stems of the withered sunflowers.

IX. Discussion on the Mechanism

What happened to the cesium contained in the roots and stems of the sunflowers before they bloomed? The author presented these results at a study session organized by Kan Gen Kon (Kansai Nuclear Council). One professor of pharmaceutical sciences shared the following comment: “The absorption of heavy metals by plants has already been investigated, but no systematic investigation has been conducted on the absorption and adsorption of cesium by plants. One possible hypothesis is that the cesium was adsorbed by the root cells of the sunflowers. If these cells lose their adsorption capacity or disappear after the plants wither, the cesium that had been adsorbed by the sunflowers would return to the soil.”

X. Tasks Ahead: Way Forward to Unravel the Mechanism

From the moment sunflowers start to form buds until they grow to a height of between 50 cm and 1 m, both their roots and stems adsorb a certain amount of cesium (2,000 Bq/kg). The radioactivity concentration surges in their roots when the sunflower plants grow quickly immediately before they bloom. Once they produce seeds and wither, however, no cesium was detected in their roots, stems, flowers, or seeds (fruits). In other words, the cesium concentrations in the respective parts of the sunflower plants change depending on the timing. The author hopes that agronomists, radiation specialists, and other scientists will one day unravel this mechanism.

These results demonstrate that soil can be decontaminated if the roots of sunflowers are collected when the plants are growing quickly immediately before they bloom.

Assuming that the sunflower roots have a circular formation, their depth and expanse (diameter) in a sunflower field are correlated. The depth of the roots ranges from 4 cm to 14 cm, and shallower roots correspond to a smaller diameter. Roots that grow to a depth of 4 cm have a diameter of between 4 and 10 cm, while roots that grow to a depth of 14 cm have a diameter of between 12 and 15 cm [4)]. Given their considerable capacity to absorb cesium, planting the sunflowers 15 cm apart (or planting 36 plants in an area of 1 m^2) should be sufficient to ensure that the roots do not interfere with one another. Considering the depth of their roots, sunflowers offer a suitable means of decontaminating shallow paddies and fields with a depth of around 15 cm.

Sunflowers can be grown twice a year in the affected areas. They should be planted at the end of April after the last frost and then harvested in July immediately before they bloom. Another planting can be made immediately after that to allow for a harvest at the end of September or October.

On December 1 and 2, the findings from this investigation using sunflowers were presented to the residents of the Jisabara District together with the idea of double cropping. On hearing these findings, the mayor of Jisabara District committed to continued decontamination using sunflowers in 2013. Further investigation will be conducted with respect to the timing of double cropping and the treatment of the harvested sunflowers.

XI. Conclusion: Effectiveness of Decontamination Using Sunflowers

Assuming that sunflower roots can adsorb 8,000 Bq/kg of cesium and that they are grown twice a year at an interval of 15 cm, 30% of the cesium can be removed from shallow paddies and fields each year.

References

1) O. Amano: Community-driven Remediation to Restore the Hamadori Region of Fukushima Prefecture: Achievements in Providing Support for Local Core Members and Addressing the Challenges Ahead [in Japanese], Journal of the Atomic Energy Society of Japan, 54 (8), 538–542, (2012).
2) Research Report by the Sunflower Decontamination Support Team, Chapter 9.1: Effectiveness of overturning the soil [in Japanese] (Hiroshi Amano).
3) Ministry of Agriculture, Forestry and Fisheries: Technical Meeting on Agriculture and Forestry, http://www.s.affrc.go.jp/docs/himawari_syobun.htm
4) Research Report by the Sunflower Decontamination Support Team, Chapter 8.6: Study on the growth of sunflowers [in Japanese] (Yasuhiko Fujii).