Strategies and Practices in the Remediation of Radioactive Contamination in Agriculture

Report of a Technical Workshop
Vienna, Austria, 17–18 October 2016

Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

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STRATEGIES AND PRACTICES IN THE REMEDIATION OF RADIOACTIVE CONTAMINATION IN AGRICULTURE

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PROCEEDINGS SERIES

STRATEGIES AND PRACTICES IN THE REMEDIATION OF RADIOACTIVE CONTAMINATION IN AGRICULTURE

REPORT OF A TECHNICAL WORKSHOP
ORGANIZED BY THE
JOINT FAO/IAEA DIVISION OF NUCLEAR TECHNIQUES IN FOOD AND AGRICULTURE AND THE
NATIONAL AGRICULTURE AND FOOD RESEARCH ORGANIZATION OF JAPAN
AND HELD IN VIENNA, 17–18 OCTOBER 2016

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FOREWORD

The fifth anniversary of the accident at the Fukushima Daiichi nuclear power plant and the 30th anniversary of the accident at the Chernobyl nuclear power plant both occurred in 2016. Both incidents were classified as major accidents at Level 7, the highest on the IAEA–Nuclear Energy Agency International Nuclear and Radiological Event Scale. From an agricultural perspective, the long term impacts of both of these accidents are related to residual amounts of caesium radionuclides in the agriculture and aquaculture environments. The radionuclide of chief concern is caesium-137 (^{137}Cs), a relatively persistent isotope with a physical half-life of approximately 30 years. Research, in laboratories and also in areas affected by radiocaesium, has focused on developing strategies and techniques to remediate and, if necessary, to ameliorate the impact of this radioactive element on agricultural production and to minimize and prevent the contamination of food and other agricultural products. Such research efforts, and the implementation of the techniques developed, assisted the social and economic recovery of affected rural communities by enabling sustainable production. However, these efforts are not widely appreciated outside the affected areas.

This technical workshop, entitled Remediation of Radioactive Contamination in Agriculture, was convened to promote and share knowledge of strategies developed and the practical experience gained in Member States for the remediation of radioactive contamination in agriculture. The workshop was planned and organized by the National Agriculture and Food Research Organization (NARO) of Japan, the Food and Agriculture Organization of the United Nations (FAO) and the IAEA. The Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture represented the two international organizations.

Representatives of the three host organizations and over one hundred technical experts from around the world participated in the workshop. An opening session was followed by a plenary session that provided an overview of key agricultural events following the accidents at the Fukushima Daiichi and Chernobyl nuclear power plants. Five technical sessions then focused on different aspects of remediation of radioactive contamination in agriculture.

The presentations and discussions at the workshop were technical and mainly focused on research and practical experience in implementing remediation activities. The majority of participants provided information related to agricultural production in Japan and in the many different countries affected by the Chernobyl accident. The workshop brought together specialists from different countries and technical backgrounds. It helped to disseminate information and knowledge in this area and produced conclusions, recommendations and observations for international organizations and countries to enhance preparedness and response planning for nuclear emergencies and radiological incidents in relation to food and agriculture. This publication contains the extended abstracts of the workshop presentations, while the accompanying on-line supplementary files contain the list of participants, all the original presentations and a list of related publications.

The IAEA is grateful to all those who contributed to this technical workshop and who helped in its planning, preparation and delivery, and gratefully acknowledges the support and hospitality extended to workshop participants by NARO. The IAEA officers responsible for this publication were C. Blackburn, G. Dercon, I. Naletoski, S. Nielen and Z. Ye of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture.

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SUMMARY

1. INTRODUCTION

The Technical Workshop on Remediation of Radioactive Contamination in Agriculture was organized jointly by the FAO and IAEA through the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture (the Joint Division) and the National Agriculture and Food Research Organization (NARO) of Japan. The workshop was held at IAEA Headquarters in Vienna, from 17 to 18 October 2016.

The workshop was attended by over 100 experts from different countries, with 28 papers presented by speakers from various professional institutions and organizations in different countries, particularly from countries in Asia and Europe with experience in dealing with the remediation of radionuclide contaminated agricultural production areas following the major nuclear accidents at the Fukushima Daiichi and Chernobyl nuclear power plants (NPPs).

The event commenced with welcoming addresses and opening statements from representatives of the three host organizations: Mr Aldo Malavasi, IAEA Deputy Director General and Head of the Department of Nuclear Sciences and Applications; Mr Qu Liang, Director of the Joint FAO/IAEA Division, representing FAO, and Mr Tokio Imbe, President of NARO. The five technical sessions covered remediation of radioactive contamination in: agriculture land and water; plants and crop products; animals and animal feeds; food and food commodities, as well as socioeconomic aspects. The contaminants discussed in detail were radionuclides of caesium, in particular ^{137}Cs as this radionuclide, above all others, affected agricultural production after the accidents at the Fukushima Daiichi and Chernobyl NPPs.

A diverse range of specialists and policy makers were brought together from authorities responsible for food and agriculture as well as from nuclear and radiation safety organizations. Question and answer sessions and lively in-session discussions also contributed to the success of the event.

2. HIGHLIGHTS OF PRESENTATIONS

2.1. Plenary Session

The Plenary Session comprised four presentations that gave a different perspective on radioactive contamination in agriculture. Two presentations provided technical overviews of the history and current situation regarding the Fukushima Daiichi and Chernobyl accidents, focusing on food and agricultural issues. A farmer from Fukushima Prefecture shared his personal experiences following the earthquake and tsunami of 2011. The fourth presentation provided a technical overview of international activities and developments in the area of radionuclides in food and agriculture.

The key agricultural events since the Fukushima Daiichi accident were highlighted in the first Plenary Session presentation. Agricultural soils, plants and animals in Fukushima Prefecture and several neighbouring prefectures were contaminated with radionuclides. The persistent contaminants of significance for agriculture were radioactive caesium (^{134}Cs and ^{137}Cs) released from the damaged NPP. Since the accident took place in March, before the rice planting season, controls on agricultural production and on the distribution of foods were quickly put in place. Production and distribution from contaminated areas were restricted as necessary. The main actions taken by the national authorities, local government institutions and relevant stakeholders to deal with the agricultural contamination from the accident were: (1) mapping soil contamination in farmland areas; (2) developing technologies for decontamination and remediation of agricultural lands based on residual contamination levels; and (3) developing technologies for reducing the soil–to–plant transfer of radiocaesium. The objectives were to identify, prioritize and ameliorate agricultural areas, so that food production could continue or resume.

A very touching and personal presentation was made by a farmer from Fukushima Prefecture. This second presentation of the Plenary Session highlighted the importance of remediation, both in terms of radiation safety and also to help alleviate the social and psychological impacts on people and communities.

As regards the Chernobyl accident, the technical overview in this session focused on the main decontamination and remediation activities since 1986 in areas affected by the accident. The presentation emphasized measures taken in the short, medium and long terms for remediation of agriculture, and the controls placed on food. It summarized the current situation in the three most affected countries — Belarus, the Russian Federation and Ukraine. Remediation measures and the lessons learnt in implementing them were discussed in detail.

The session closed with a presentation that gave an overview of current Joint FAO/IAEA Division activities related to the control of radionuclides in food and agriculture, including the development of technologies for managing contaminated agricultural lands and recent international standards and guidance for monitoring, assessing and controlling food and agriculture contaminated with radioactivity.

The Plenary Session set the scene for the five technical sessions that followed: (i) Agricultural Land and Water; (ii) Plants and Crop Products; (iii) Animals and Animal Feeds; (iv) Food and Commodities; and (v) Socioeconomic Aspects. Presentations and discussions focused on research results and practical experience from Japan and from countries affected by the Chernobyl accident.

2.2. Agriculture Land and Water (Technical Session 1)

This session commenced with a presentation on the dynamics of radionuclides of caesium in agro-environments in Japan. It provided information on experiments to investigate and measure the factors that influence changes in concentrations of caesium radionuclides (^{134}Cs and ^{137}Cs) in agricultural soils in the prefectures of Fukushima, Ibaraki, Tochigi and Miyagi. It showed how the results of experiments to calculate the radiocaesium interception potential (RIP) for caesium sorption on different soils, together with detailed maps of caesium radionuclide levels in farmland soils in Japan, can be used to predict future changes in caesium levels in different soils. New insights about caesium dynamics in soils also indicated a need for improvements in the modelling of caesium soil sorption and crop uptake of caesium.

A presentation from Ukraine introduced the national experience in remediation of contaminated farmlands after the Chernobyl accident, including monitoring radiation, developing and implementing permissible levels (PLs) for radionuclides, and applying numerous effective countermeasures for remediation of the nuclear and radiological contamination in agricultural production. All agricultural countermeasures implemented on a large scale for contaminated lands after the Chernobyl accident can be recommended for use in the case of future accidents. However, the effectiveness of most soil based countermeasures was found to vary at different locations. Therefore, the analysis of soil properties and agricultural practices before the application of countermeasures is of great importance.

A third presentation focused on topsoil removal techniques used in Japan and the development of special tractor mounted machines. The presentation illustrated techniques for the removal of topsoil (3–6 cm in depth) by mechanized shovelling or skimming. Removal of topsoil from fields can significantly reduce the inventory of radionuclides available for uptake into agricultural commodities. Progress in developing machines and self-propelled vehicles was discussed. The gradation of contaminated lands by caesium contamination level and the application of soil removal techniques, as either a one step action to remove the topsoil (approx. 4–5 cm) or a two step activity of scrape–and–skim to remove soil to a similar depth, can be used to improve the overall efficiency of the remediation process. The two step activity to remove topsoil involved first using a machine to scrape soil to a depth of approximately 4 cm followed by a soil skimming machine that not only scraped away a further 1 cm depth of topsoil, but also scooped up this soil and the soil from step 1 and transferred it into a collection vehicle, so that it could be transported away.

Integrated approaches for modelling and assessing the transfer of caesium radionuclides from the soil into soil solution and then into plants were also presented at this session.

The different techniques used to remediate agricultural land were discussed, as were the advantages and limitations of tools to aid remediation activities and the experience gained in areas affected by the Chernobyl as well by the Fukushima Daiichi accidents.

2.3. Plants and Crop Products (Technical Session 2)

Physical, agrochemical and plant based measures were discussed as management approaches to remove radionuclides from soil or reduce the rate of transfer of radionuclides into crops and thereby facilitate the return of affected land to agricultural production after a nuclear accident. The effectiveness and feasibility of such approaches were considered. Studies on the soil–to–plant transfer of radiocaesium have shown that the transfer and accumulation of caesium can be predicted to a reasonable degree if various soil and plant parameters are known. Alternative land uses, such as growing varieties less able to accumulate radionuclides or producing non-food crops, are potential approaches to revitalize contaminated agricultural land. Also, land uses not based on soil may provide feasible alternatives to conventional agricultural production (e.g. aquaculture, greenhouse production possibly in combination with solar collectors for the commercial generation of electricity), and these alternatives have been considered by some for recovering contaminated land.

Results from a collaborative project on the development of physico-chemical and biological technologies for the remediation of agronomic soils contaminated with caesium were presented. Research into new plant varieties with reduced abilities to uptake radiocaesium from contaminated soil was also reported.

Other presentations at this session included studies on the physiology of caesium uptake by paddy rice in comparison with uptake by upland rye grass. Research into the effectiveness of inoculating roots with potassium solubilizing bacteria to influence plant radiocaesium accumulation was also reported as a management option for crop production on caesium-contaminated soils. Research indicates that such inoculation promoted plant growth and increased the overall plant biomass. Radiocaesium accumulation was observed to be significantly greater in roots than in shoots.

2.4. Animals and Animal Feeds (Technical Session 3)

A comprehensive system for the early detection of radioactive contamination in animals and animal products was presented. Contingency plans for the remediation of radioactive contamination in animal production systems aim to prevent contaminated products from entering into the food supply chain. Response measures based on the experience gained after the Chernobyl accident were presented as a comprehensive package and included corrective monitoring of farm inputs (animal feeds and water supply), the application of caesium binders to decrease the transfer rate of caesium into milk and meat, altering the type of production (i.e. changing from milk to meat production) and the processing of animal products to further decrease activity concentrations in consumer ready products.

It is reported that the application of potassium rich fertilizer to pasture is important for controlling radiocaesium concentrations in forage on renovated grassland and this was observed through extensive research on renovated grasslands in the Fukushima area.

Other presentations included reports on the influence of seasonal factors on levels of radioactivity in crops following short term deposition of radionuclides to agricultural land, and on the effectiveness of countermeasures implemented in agriculture production to ensure the compliance of animal products with permissible radionuclide concentrations levels in foods.

2.5. Food and Commodities (Technical Session 4)

A detailed presentation provided an overview of how food has been managed following the Chernobyl accident and focused mainly on the affected areas that were formerly in the USSR but subsequently became parts of Belarus, the Russian Federation and Ukraine. Countermeasures applied to production in agricultural areas after the Chernobyl and Fukushima Daiichi accidents were considered, the importance of monitoring and taking early actions to restrict food distribution and therefore protect consumers was highlighted, as were methods for further reducing radionuclide content in food.

The influence of food processing and cooking on radiocaesium content was also discussed in the context of research in Japan that focused on grains and legumes (brown rice, wheat, buckwheat, soya bean) produced in contaminated areas.

2.6. Socioeconomic Aspects (Technical Session 5)

A presentation by NARO gave details on the current situation in the affected area in Fukushima Prefecture and included key past events. Another presentation on the socioeconomic and environmental impacts, and future prospects, was given to update workshop participants on international recovery and development projects related to the countries affected by the Chernobyl accident. These presentations stimulated a great deal of discussion and raised awareness about the actions of different international organizations and their cooperation in providing assistance. The session closed with a thought-provoking presentation on an economic project to investigate the work structure of farming households in affected areas in Japan as a means of helping in the restoration of farming and communities.

3. CONCLUSIONS

The workshop participants helped to prepare the following general conclusions, recommendations and observations. These are intended as key, general points to help enhance, in the future, preparedness for and responses to nuclear emergencies and radiological incidents related to food and agriculture.

3.1. Residual levels of radioactivity in agriculture

Residual levels of radioactivity can persist for a long time following a nuclear emergency. Agriculture, fisheries and forests are vulnerable. Although ‘low probability events’, such emergencies are high impact.

Nuclear or radiological accidents can have regional, international, or even global consequences on food and agriculture as well as on food trade. Substantial releases of radionuclides have significant long term consequences for people and their livelihoods. This type of event is infrequent, but experience gained from severe radiological accidents demonstrates that agriculture production, food processing and trade (including crops, forestry and fisheries) are vulnerable sectors.

Procedures for dealing with such events should be included in national plans for dealing with emergencies, including the plans of agricultural, fishery and forestry departments.

3.2. Psychological impact of nuclear or radiological accidents on farmers

The psychological impact of contamination in agriculture should not be overlooked. Remediation not only improves radiation safety (reduces dose) and restores economic productivity — it also ‘lifts morale’.

Should agriculture become contaminated, the psychological impact on farmers and other ‘producers’ can be devastating. Radiation safety, the local economy and community spirit can be improved by:

- Timely and efficient communication and the provision of information;
- ‘Self-help’, such as providing facilities to self-check radionuclide levels;
- Access to good measurement data;
- Efforts to involve the community in practical actions to reduce radioactivity levels.

3.3. Remediation methods to mitigate radioactivity in agriculture

Many different remediation methods have been developed and used in practice, mainly following the two major NPP accidents (and to address residual levels of ^{137}Cs contamination).

Various chemical, physical and biological methods have been developed and used to mitigate radioactivity levels in agriculture to protect consumers and increase the resilience of farmers, fisherpeople and forest users. There is a considerable amount of expertise in this area, but it is generally concentrated in regions affected by past accidents. This expertise has mainly been developed to deal with radiocaesium contamination following the accidents at the Chernobyl and Fukushima Daiichi NPPs.

3.4. Research and technology development after nuclear or radiological accidents

There is a need to preserve and maintain the research and technology developed after the Chernobyl and Fukushima Daiichi accidents to remediate radioactive contamination in agriculture so that it can be made available to other countries, and can be used by future generations, if necessary.

3.5. Communication and coordination for better remediation

In the 25 years that elapsed between the Chernobyl and Fukushima Daiichi accidents, the internet and social media have brought about a fundamental shift in how information and data are collected, presented and accessed.

Official bodies should be aware of the growing tendency for citizen initiatives (e.g. citizen science networks and social media). Technology is enabling private individuals to build networks and contribute to scientific research. The scientific rigour (e.g. data quality, calibration, quality assurance), and therefore the technical value for remediation, rely on coordination and guidance to ensure that measurements are appropriate and accurate. There is a great opportunity for using such initiatives to engage and work with producers and consumers directly.

4. GENERAL RECOMMENDATIONS

4.1. Build capacities for monitoring and mapping radioactivity in agriculture

The ability to monitor and map radioactivity in agriculture is fundamental. Systems to monitor and map radioactive contamination in agriculture, readily visualize the extent of the problem and assist in decision making are essential for the remediation of radioactive contamination in agriculture. The development of standardized systems and protocols should be encouraged through national, regional and international collaboration. For example, the Joint FAO/IAEA Division is working with experts in Member States to develop and improve technology packages that can be transferred to agricultural (including food, fisheries and forestry) organizations in different countries and help improve capabilities to monitor radioactive contamination.

Timely and informed reporting of monitoring results are as important as data collection. Methods to present monitoring results and data must be accessible to ensure that appropriate information is available to producers and members of the public. Stakeholder participation is necessary to ensure that actions are implemented that are both radiologically sound as well as acceptable to the people concerned.

4.2. Establish expert networks on remediation of radioactive contamination in agriculture

A network of specialists who are expert in different aspects of remediation of radioactive contamination in agriculture should be established so that know-how can be maintained, improved and transferred to others.

This Technical Workshop brought together experts from many different countries. These participants could form the core of a network that can work together to develop and transfer skills and remediation methods in agriculture. It is important that technical workshops and meetings in this area of remediation of radioactivity in agriculture are convened in the future to foster further collaborative efforts.

4.3. Support research and development of remediation technology

Research and development in the remediation of radioactive contamination in agriculture is a specialist area and needs to be supported and encouraged. Capacity building is also important to ensure that the know-how is transferred to other countries and maintained.

Experience clearly shows that no two large scale contamination events (nuclear accidents) are exactly the same, but there can be general commonalities. When radionuclides are released into the environment, agriculture can be affected and it may take a long time to recover from the effects. Therefore, international collaboration and research are necessary to ensure that remediation methods are based on sound scientific understanding and are developed and maintained, so that they can be applied in future. The workshop participants believed that more collaborative research efforts in this area would be beneficial.

4.4. Enhance transfer of knowledge on remediation

Know-how on remediation and the provision of such procedures in official emergency (disaster) management plans should be encouraged.

The involvement of agricultural, fishery and forestry departments and key specialists is important for the transfer of knowledge and the development of procedures on remediation measures in production. The integration of procedures in general emergency management plans and transfer of knowledge on remediation measures should include those involved in food and commodity production, including animal production systems.

4.5. Promote public participation in remediation activities

Remediation activities need to involve local stakeholders (farmers, fisherpeople, etc.) and the community as a whole.

Organizations should engage closely with local stakeholders when developing and implementing remediation efforts. This includes working formally with stakeholders such as producers, farming/fishing bodies, academia and community groups. It may also involve more informal approaches using social media and ‘citizen science networks’ to engage and work with people directly.

5. OBSERVATIONS

5.1. Limitation and restriction of contaminated food materials

The initial limitation and restriction of contaminated food, milk, water and animal feed can successfully and substantially reduce internal radiation doses to the population.

5.2. Early application of remediation measures

The early application of suitable remediation measures can also substantially reduce internal doses to the population. It can also return agricultural land back to production or enable other economic activities.

5.3. The importance over the long term of the dynamics of caesium in the agricultural environment

- The early removal of contaminated soil and plants is a very effective remediation measure. However, this may create large amounts of unwanted soil and biomass. Therefore, it may not be appropriate in all situations.
- The behaviour of Cs in soil depends on soil type, mineral and organic content.
    - Soil to plant transfer can be regulated by potassium (in the case of Cs).

    - There is also a need to consider Cs transfer factors for different crop species (and varieties).
    - Phytoremediation is not recommended because it is not efficient, has low accumulation capacity compared with soil, and could lead to the production of large amounts of low contaminated biomass).
- Alternative crop production (biofuel, ornamental plants, fibre, etc., in place of food) is also an alternative remediation measure. However, this may force communities to alter or abandon their traditional way of life.
- The addition of Cs binders in animal feed is effective in decreasing contamination in milk and meat.
- Food processing and preparation methods can also further decrease radioactivity in the diet.

5.4. Communication and participation

Communication and engagement with producers and others in the local community are important for stimulating wide participation in community-area based development.

5.5. Setting standard levels

Establishing and working to clear numerical limits (e.g. radionuclide concentrations) is necessary. Standard setting is important, especially if radioactive contamination affects agriculture in neighbouring countries.

OPENING SESSION

Chairperson

Z. YE
Joint FAO/IAEA Division of Nuclear Techniques
in Food and Agriculture

OPENING ADDRESS

A. Malavasi
Deputy Director General,
Department of Nuclear Sciences and Applications,
International Atomic Energy Agency,
Vienna

Distinguished guests, ladies and gentlemen, workshop participants,

Welcome to Vienna, welcome to the IAEA and this International Technical Workshop on Remediation of Radioactive Contamination in Agriculture.

The year 2016 marks the fifth anniversary of the accident at the Fukushima Daiichi nuclear power plant and the 30th anniversary of the accident at the Chernobyl nuclear power plant.

Research and know-how on remediation gained in the aftermath of these accidents has created a body of experience to support the recovery of agricultural production and rural development in the affected areas. Those countries that have been affected by such events have been working hard to remediate the situation and have gained valuable insights and experience. There is a need to promote and share this knowledge.

This workshop, in particular, is promoting practical remediation activities. An appreciation of developments in this area will greatly improve emergency preparedness related to food and agricultural production.

I would like to remind you that this workshop is hosted by the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture (NAFA) in collaboration with Japan's National Agriculture and Food Research Organization (NARO).

I am sure you will have an interesting workshop over the next two days and I wish you all success in identifying lessons learned and recommendations for the future.

Ladies and gentlemen, once more, welcome to the IAEA and thank you.

OPENING ADDRESS

Q. Liang
Director,
Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture,
International Atomic Energy Agency,
Vienna

Ladies and gentlemen, distinguished guests, dear colleagues,

I am very happy that this meeting has been arranged by the National Agriculture and Food Research Organization (NARO) of Japan, the Food and Agriculture Organization of the United Nations (FAO) and the International Atomic Energy Agency (IAEA).

On behalf of FAO, I extend my warm welcome to all of you and hope that this is a successful and fruitful workshop.

I would like to thank the IAEA for providing this venue and platform where we can discuss strategic issues related to remediation of radioactive contamination in agriculture.

We are here to focus on agriculture — radioactive contamination can be far reaching. Contamination does not respect boundaries and can affect all aspects of production, supply, national and international trade.

Remediation of radioactivity in agriculture aims to minimize and prevent the contamination of foods and produce. In doing so, it assists the social and economic recovery of affected communities by enabling sustainable production.

However, remediation efforts are not widely known outside of the affected areas. Remediation includes many disciplines from soil, water, crop, animal, food and social sciences working for a common objective.

The workshop is expected to:

- Strengthen understanding of current remediation measures;
- Bring together experts in the field, and;
- Identify knowledge gaps and research needs.

Ladies and Gentlemen, I am very happy to be with you today. On behalf of the FAO, I wish you every success.

OPENING ADDRESS

T. Imbe
President,
National Agriculture and Food Research Organization,
Japan

On behalf of the National Agriculture and Food Research Organization (NARO), I would like to welcome all the participants of the 'FAO/IAEA–NARO Technical Workshop on Remediation of Radioactive Contamination in Agriculture'. I would also like to express my sincere gratitude to the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture for hosting this workshop in collaboration with NARO, and giving us a great opportunity to share our research results on the reconstruction and revitalization of agriculture and livelihood in areas affected by the accident at the Fukushima Daiichi nuclear power plant. As Japan's main public research organization for research and development in food and agriculture, NARO is taking a leading role in investigating the effects of the nuclear accident on farmlands and agricultural activities in disaster affected areas.

Five years have passed since the Great East Japan Earthquake accompanied by a huge tsunami struck the Tohoku region leaving 15 894 people dead and 2562 people still missing. The tsunami also destroyed the Fukushima nuclear power plant, causing extensive damage to vast farmlands due to contamination by radiocaesium. Immediately after the disaster, NARO started to investigate the damage from the accident and to pursue research initiatives aimed at decontaminating the affected farmlands and reducing the adverse effect of radioactive contamination on crops. We established the Agricultural Radiation Research Centre in Fukushima Prefecture as a branch of the Tohoku Agricultural Research Centre, and started collaborations with the Fukushima Agriculture Technology Centre, universities, and the private sector to accelerate the recovery of agricultural production and people's life there.

In this workshop, several NARO scientists will present our key findings and technologies for the reconstruction and revitalization of agriculture, and a farmer from Fukushima Prefecture will present the current situation in farmlands affected by the nuclear disaster. At the same time there will be presentations in food and agricultural management associated with the Chernobyl nuclear accident. Exchange of information and discussion in this workshop will contribute to our ongoing recovery projects in Fukushima. We are looking forward to not only sharing the results of our studies, but also gaining new perspectives from the participants on how to tackle the enormous task ahead of us.

And I would like to extend my sincere appreciation to the staff of both FAO/IAEA and NARO who were involved in organization of this workshop. Again, thank you very much for your participation and wishing you all a very stimulating workshop in the next two days.

PLENARY SESSION

Chairperson

Z. YE
Joint FAO/IAEA Division of Nuclear Techniques
in Food and Agriculture

TECHNICAL OVERVIEW OF KEY AGRICULTURAL EVENTS SINCE THE FUKUSHIMA DAIICHI NUCLEAR POWER PLANT ACCIDENT IN 2011

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Abstract

After the serious accident at Tokyo Electric Power Company's Fukushima Daiichi (No. 1) nuclear power plant, an intensive soil contamination survey was undertaken (about 3400 survey points from 15 prefectures) and a contamination map was released on 23 March 2012. The map served as a basis for decontamination of agricultural lands and crop cultivation plans. The decontamination technologies for contaminated agricultural lands (including paddy fields) suited to different soil contamination levels were also devised. Application of potassium to the soil to reach 25 mg K_2O per 100 g of exchangeable potassium concentration in soil for rice and soybean production and 30 mg K_2O per 100 g in soil for buckwheat production was shown to be effective to reduce the radiocaesium concentration in grain at harvest to below the regulation limit of general foodstuffs (100 Bq/kg). This potassium application was carried out in agricultural lands in and around Fukushima Prefecture, and contributed to a drastic reduction in the number of brown rice bags exceeding the regulation limit.

1. INTRODUCTION

The tsunami caused by The Great East Japan Earthquake on 11 March 2011 resulted in a serious accident at Tokyo Electric Power Company's Fukushima Daiichi (No. 1) nuclear power plant. Agricultural plants and soils in and around Fukushima Prefecture were contaminated with radiocaesium (^{134}Cs and ^{137}Cs) released from the damaged nuclear power plant. NARO (including the former National Institute of Agro-Environmental Sciences) took the following actions in response to the accident in collaboration with the Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF), local governments in affected areas including Fukushima Prefecture, universities and private companies. Contamination of agricultural soils and plants caused by the nuclear accident was summarized in Ref. [1].

(1) Mapping soil contamination in farmland areas.
(2) Developing technologies for decontamination of agricultural lands, depending on the contamination levels.
(3) Developing technologies for decreasing the soil to plant transfer of

radiocaesium.

2. MAPPING SOIL CONTAMINATION IN FARMLAND AREAS

Surveying contamination levels in soil and making a contamination map of agricultural lands was the most important task just after the accident. The first contamination map (about 580 survey points from six prefectures including Fukushima) was released from by MAFF on 30 August 2011. Thereafter, the map was updated four times. The most intensive survey was conducted, and the second contamination map (about 3400 survey points from 15 prefectures) was then released on 23 March 2012 (Fig. 1) [2]. The information provided by the contamination map was used for developing strategies for the decontamination of agricultural lands and also for deciding whether crop cultivation for that year was possible on a field by field basis.

3. DEVELOPING TECHNOLOGIES FOR DECONTAMINATION OF AGRICULTURAL LANDS

The Tohoku region in eastern Japan, including Fukushima Prefecture, is an area of paddy rice, common arable crops (e.g. soybean and buckwheat), forage, vegetables and fruit production. As a result of the nuclear power plant accident, large areas of agricultural lands were contaminated by radiocaesium and technologies for decontamination of agricultural lands suited to soil contamination levels were being sought.

For agricultural lands that were not cultivated after the nuclear power plant accident, removal of topsoil was efficient in reducing air dose rates at 1 m height. For agricultural lands that were not contaminated intensively (<5000 Bq/kg of radiocaesium concentration in soil), inversion tillage by ploughing was effective in reducing air dose rates. The effects were more pronounced for soils that were not cultivated (reductions by 68−87%) than for soils that were already cultivated after the accident (reductions by 28−56%). Unlike in the Chernobyl accident, paddy rice fields were contaminated by radiocaesium in the Fukushima Daiichi accident (at the time of the nuclear power plant accident, rice plants were not under cultivation). In paddy fields that were not contaminated intensively, rice cultivation was permitted in 2011, but brown rice exceeding the regulation limit of general foodstuffs was produced. For those paddy fields, decontamination technology involving removing floating clay after soil puddling (agitation of soil suspension before transplanting rice seedlings) was developed. This technology is based on the natural tendency of caesium to bind to clay minerals in soil and become unavailable for uptake into plants. For efficient decontamination work in agricultural lands, decontamination machines based on tractor or tractor implements were devised, and instruction manuals were also released.

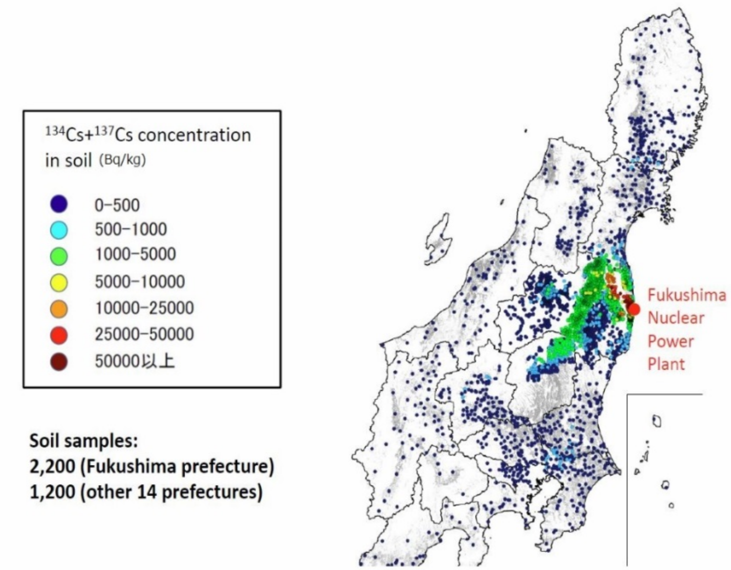

FIG. 1. The distribution of radioactive Cs concentrations in agricultural soils (released on 23 March 2012 by MAFF [2]*).*

4. DEVELOPING TECHNOLOGIES FOR DECREASING SOIL TO PLANT TRANSFER OF RADIOCAESIUM

It has been shown that potassium (K^+) applied to soil reduces radiocaesium concentrations in agricultural products grown on that soil. The relationships between potassium concentration in soil and radiocaesium concentration in agricultural products were examined for paddy rice, soybean and buckwheat by using the results from field experiments conducted in and around Fukushima Prefecture after the accident (Fig. 2) [3]. Diverse soil samples with soil type and clay mineral composition existed in the affected areas, but the application of potassium to the soil to reach 25 mg K_2O per 100 g of exchangeable potassium in soil for rice and soybean and 30 mg K_2O per 100 g of exchangeable potassium in soil for buckwheat was shown to be effective to reduce the radiocaesium concentration in grain below the regulation limit of 100 Bq/kg for general foodstuffs. This potassium application was carried out on agricultural lands in and around Fukushima Prefecture, and contributed to a drastic reduction in the number of brown rice bags that exceeded the regulation limit

(0.0007% of about 10 million rice bags) in 2012, the second year of rice cultivation after the accident.

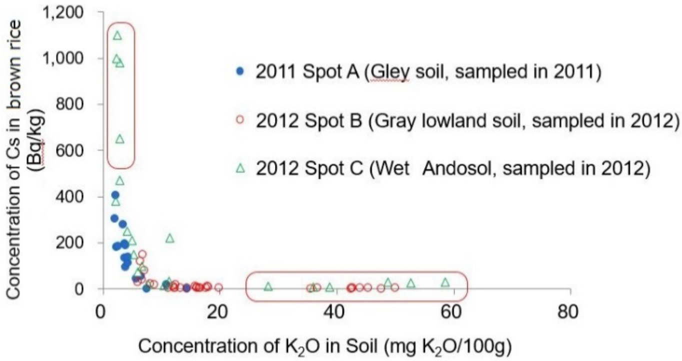

FIG. 2. The relationship between exchangeable potassium concentration in soil and radioactive Cs concentration in brown rice. [3]

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CHERNOBYL: MAIN HIGHLIGHTS OVER 30 YEARS AND THE CURRENT SITUATION

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Abstract

Extensive remediation was conducted on contaminated landscapes after the Chernobyl accident in 1986. A brief review of the main features of the contaminated landscape, exposure pathways and subsequent remediation is given. The current situation and lessons learned are also considered.

1. INTRODUCTION

The information given here is largely based on the IAEA Chernobyl forum report [1] and additional, relevant literature from the last decade up to 2016 [2–6]. The estimated atmospheric release of radionuclides from the Chernobyl nuclear power plant (NPP), which can be important contributors to the internal and external doses arising from agricultural activities, in PBq, was 1760 of ^{131}I; 47 of ^{134}Cs, 85 of ^{137}Cs and 10 of ^{90}Sr. Short-lived radioiodine isotopes were particularly important in the emergency phase and countermeasures were put in place to reduce doses. However, exposure to radioiodine in milk was significant, leading to thyroid cancers. ^{90}Sr was largely deposited within the exclusion zone. After the emergency phase, ^{134}Cs and ^{137}Cs were the most important long term dose-forming radionuclides.

2. CONTAMINATION AND CHARACTERIZATION OF AGRICULTURALLY PRODUCTIVE LAND

The estimated total deposition to terrestrial and freshwater ecosystems in Europe was 64 PBq and the area with ^{137}Cs deposition >100 kBq/m^2 was 56 000 km^2. Much of the contaminated, flat, landscape around Chernobyl was sparsely populated and constituted agricultural land with small settlements, rivers and lakes, and forests. The areas that were most highly contaminated by the Chernobyl accident were largely used for agriculture by collective farms and for forestry enterprises. Less productive land forests and lakes were used by local households to produce or harvest much of their own food. The most important agricultural products were milk, meat, grain and potatoes. The Chernobyl accident occurred when the growing season had commenced and agricultural animals were grazing on pasture.

3. ENVIRONMENTAL PATHWAYS — WHICH PRODUCTS WERE CONTAMINATED?

Both external and internal exposure pathways were important after the Chernobyl accident. External pathways were relatively more important for forest workers, agricultural workers and people living in more highly contaminated areas. The importance of internal exposure pathways for agricultural, freshwater bodies, forestry products and wild food from forests was highly dependent on the soil type and was often relatively high compared with previously reported data. Doses from terrestrial foodstuffs were generally more significant than those from drinking water and aquatic foodstuffs.

The importance of soil characteristics in determining the spatial variation in the extent of radiocaesium transfer to food products was identified after the initial period, when interception dominated. A common feature of many of the most contaminated areas where radiocaesium transfer to food was high was the presence of soil types with low sorption of radiocaesium (termed radioecologically sensitive [7]) leading to high radiocaesium transfer rates from soil to plants and then animals.

The importance of extensive systems in contributing to internal doses to human was identified. Radiocaesium transfer was particularly high to mushrooms, berries, some freshwater fish, wild game animals, and reindeer in both the USSR and the Former Soviet Union and parts of Europe. Furthermore, local households acquired much of their diet from extensive areas with low fertility soils leading to high radiocaesium transfer. A key feature of such soils was that radiocaesium transfer remained relatively high for decades after the accident. Natural products such as mushrooms, berries, freshwater fish and privately produced milk for some rural people substantially contributed to the radiation dose received by humans especially to rural populations within the former Soviet Union. While consumption of such foodstuffs was banned in some areas, compliance was often poor.

4. REMEDIATION MEASURES ADOPTED

After the accidents the initial goal of recovery was the reduction of dose to humans. The temporary permissible levels for effective annual dose reduced from 100 mSv in 1986 to 30 mSv in 1987, 25 mSv in 1988−1989 and 1 mSv in 1991 and onwards. The long term goal from 1991 onwards was an additional annual effective dose to the public of <1 mSv. It was also to enable residents of contaminated areas to return to a normal life. Temporary permissible levels (TPLs) for radionuclides in food were established which were gradually reduced with time.

The radiation dose to members of the public to be used for remediation purposes cannot be easily measured, so operational, easily measurable quantities were used, including ambient gamma dose rates (μSv h^{-1}) and deposited ^{137}Cs per unit area

(Bq m^{-2}) or per weight (Bq kg^{-1} dw soil). Restrictions were introduced on food production and consumption and extensive food monitoring was carried out. After the Chernobyl accident, the contaminated areas were subdivided into different categories of remediation according to ground deposition bands shown in Table 1. The definition of contaminated land was set at 37 kBq m^{-2}, giving rise to an individual annual effective dose of 1 mSv.

TABLE 1. DESIGNATION OF REMEDIATION ACTIVITIES ACCORDING TO ^{137}Cs GROUND DEPOSITION AFTER THE CHERNOBYL ACCIDENT [8]

^{137}Cs (kBq m^{-2})	Designation of remediation activities
Below 37	Not contaminated.
37–185	Remediation for areas with 'sensitive soils' (e.g. wet peat
185–555	or acidic sandy soils).
555–1480	Remediation for sandy soils and light loam soils.
>1480	Full scale remediation.
	No economic activity.

Hundreds of thousands of people were living in these areas, giving rise to individual annual effective doses of >1 mSv. All settlements with an average annual effective dose of 1 mSv were remediated to allow production of food with contamination below the permissible levels and reduce their effective dose rate. This was closely linked with ensuring sustainable economic activity in the affected areas.

A risk based approach was implemented to develop the remediation strategy. Optimization, taking into account the cost–benefit weighting of averted dose versus remediation costs, was an important part of the remediation strategy. Agricultural land was remediated by treating with additional K and P, liming, Cs sorbents and organic fertilizers and drainage of peats. Radical improvement of agricultural land was achieved by combining ploughing, reseeding and additional fertilization, and was particularly effective in improving the fertility of the land and reducing radiocaesium uptake into fodder and other crops. There was a particular focus on remediation measures for animal products as milk and meat consumption was a major component of the ingested dose. Many different measures were tested for animal products, including clean feeding to decontaminate animals prior to slaughter. Live monitoring procedures were developed as part of this measure. Caesium binders, especially hexacyanoferrates, given via different delivery systems to domestic and free ranging animals, were also developed to reduce the absorption of radiocaesium in the gut of ruminants.

There were restrictions on access to the contaminated forests, the harvesting of food products (such as timber and wild food) and the collection of firewood. Local monitoring facilities were provided for people to check the radiocaesium content of forest products. An optimization approach was adopted whereby site specific settlement information was provided on the spatial and temporal variation in radiocaesium contamination of forest products. Guidance was provided on which mushroom species to avoid, where and when to collect wood, wild products and hunting game animals, and on the modification of tree felling schedules. Remediation of lakes by the addition of lime was not effective in reducing radiocaesium activity concentrations in fish.

It became clear that selection of remediation options needs to take account of many factors, including effectiveness, feasibility, practicality, costs, waste generation, side effects, social aspects and relevant experience. Freely available datasheets were developed which evaluated these aspects for more than 100 remediation options.

5. THE CURRENT SITUATION

In the first five years after the Chernobyl accident, the goal of remediation was dose reduction. Much of the focus of the mid–long term remediation strategy was on reducing internal pathways. The approach taken in the three highly contaminated countries varied after the USSR split into separate countries at the end of 1991. The three countries of the former Soviet Union developed catalogues for each remediated settlement containing the annual effective doses due to both external radiation and ingestion of radiocaesium, strontium and plutonium. The maximum effect from countermeasures and remediation was achieved in 1986−1992. Since 1991, the proportion of animal products with radiocaesium activity concentrations exceeding action levels has been <10% of the gross output from contaminated areas. Because of financial constraints in the mid-1990s, the use of agricultural countermeasures was considerably reduced. Application rates were inadequate for both conventional food production and remediation so some increase in ^{137}Cs transfer occurred. Nevertheless, remediation is still ongoing in some areas where there is still high radiocaesium transfer from soil to vegetation. While cost benefit–analysis was a key factor during the first decade after the accident, the importance of considering social aspects increased thereafter. The long term adherence to banning the collection and/or consumption of products has decreased. In response, there is a focus on providing readily understandable information and guidance on how people can reduce their personal radiological risk.

6. LESSONS LEARNED, THEIR DISSEMINATION AND RELEVANCE WORLDWIDE

Some of the many lessons learned are given here:

(a) The USSR had ready access to a large number of skilled radiation protection scientists at the time of the Chernobyl accident who had worked on the Kyshtym accident. The availability of people with relevant remediation expertise was an important resource for developing and implementing the remediation strategy.
(b) Remediation may be required for many years after contamination occurs, depending on the soil types and agricultural production characteristics of the contaminated area.
(c) Soil type can be just as important as the extent of radionuclide deposition in defining areas that may need to be remediated for a long time.
(d) Models which quantify the spatial and temporal variation in radionuclide behaviour are a valuable resource for optimizing remediation efforts.
(e) Remediation options that are most appropriate to be adopted are specific to the soil type, agricultural production type, environmental context and social and cultural perspectives. One solution does not fit all.
(f) Live monitoring and clean feeding of animals are highly cost effective, acceptable and practical. Used in combination, they help avoid the unnecessary slaughter of livestock.
(g) For forestry production, account must be taken of factors leading to variation in both external and well as internal exposure pathways.
(h) Remediation of aquatic systems were not very effective in reducing doses from the consumption of aquatic food.
(i) Waste generation can be a costly and time-consuming consequence of remediation and must be considered prior to wide scale application of a remediation option.
(j) Locally based monitoring and information resources, including trusted local professionals, are important and effective parts of the remediation strategy.
(k) A remediation strategy should take account of radiological and cost effectiveness, but should also consider the acceptability of different options, especially to the workers and residents in contaminated areas. Social and ethical perspectives may vary considerably between different countries.

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DESPAIR AND HOPE AFTER THE NUCLEAR ACCIDENT IN 2011

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SUMMARY

The 2011 accident at the Fukushima Daiichi nuclear power plant led to the evacuation of the population, a range of social and psychological difficulties for the evacuees, and severe economic losses due to the loss of livelihoods of many residents, including farmers. Given the possibility that agricultural activities can be restarted if decontamination techniques are implemented, test farming has been initiated which has shown that safe rice can be grown. However, it is recognized that this rice may not find a ready market given the perception that it was grown in a contaminated area. In addition, the return of people capable of continuing farming activities is in doubt. Despite these obstacles, soil cultivation should be allowed to continue to restore the area to its previous condition.

CONTROL OF RADIONUCLIDES IN FOOD AND AGRICULTURE

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Abstract

As parties to two international conventions governing notification and assistance in the event of nuclear or radiological emergencies, the FAO and IAEA play a major role in international emergency response arrangements. A key activity of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture (Joint FAO/IAEA Division) in an emergency is to help provide Member States with information about radionuclides in food and agriculture, and to offer assistance and support to countries concerning the radiological consequences for food production. The paper explains the role of the Joint FAO/IAEA Division in nuclear emergency preparedness and response and gives examples of two current activities. Firstly, it highlights an international research project for developing food and soil data collection and analytical protocols, and state of the art information systems for both routine monitoring and also in emergency response to nuclear and radiological incidents. Secondly, the paper gives more information about the role of the Joint FAO/IAEA Division in implementing normative standards and guidance related to radioactivity in food, through the Codex Alimentarius Commission and the Codex Committee on Contaminants in Food.

1. INTRODUCTION

Accidental or malicious releases of radioactivity have the potential to threaten health and disrupt life. Communities, agricultural production and food trade can be severely affected with global consequences for consumers, producers and traders. It is important that countries are aware of the importance of contingency planning. It is also important that support for agricultural departments and arrangements for dealing with contaminated land and agricultural products are available.

In line with their mandates, international organizations provide assistance to their Member States. Where knowledge or technological gaps are identified, the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture (Joint FAO/IAEA Division) can coordinate research efforts to develop and maintain appropriate technologies and make the fruits of these research efforts available to countries that need technical support.

2. ROLE OF THE JOINT FAO/IAEA DIVISION

The FAO, through the Joint FAO/IAEA Division, is part of an international system to facilitate the provision of information on radioactivity, especially radionuclides in food and agriculture, in order to minimize radiological consequences following a radiological or nuclear emergency.

The FAO and IAEA are full parties to two international conventions governing notification and assistance in the event of nuclear or radiological emergencies. These conventions establish the emergency preparedness and response framework and both were adopted in 1986, following the accident at the Chernobyl nuclear power plant.

In addition, the Joint FAO/IAEA Division can provide assistance and support in situations where residual levels of radionuclides contaminate agriculture, e.g. long after a nuclear emergency. Although this is not an emergency response function, it falls within the mandate of the Joint FAO/IAEA Division because it is an FAO and IAEA activity related to the nuclear sciences and food and agriculture.

3. DEVELOPING TECHNOLOGIES FOR MANAGING CONTAMINATED AGRICULTURAL LANDS

Current activities include an international research project, involving ten countries, to develop and assess innovative data collection and analytical protocols, and state of the art information systems that can be used for both routine monitoring and also in emergency response to nuclear and radiological incidents that could affect food and agriculture.

Presently, there are no internationally established protocols for large scale food monitoring and analysis, or information systems available that assist Member States in decision making, at different stakeholder levels, to keep food and agriculture safe during nuclear or radiological emergencies. The targeted protocols or information system can be used by agricultural departments and, as the information system stores data on radioactivity in food that are georeferenced and time-stamped, helps them map and contain areas where radionuclide levels would be unacceptable (Fig. 1).

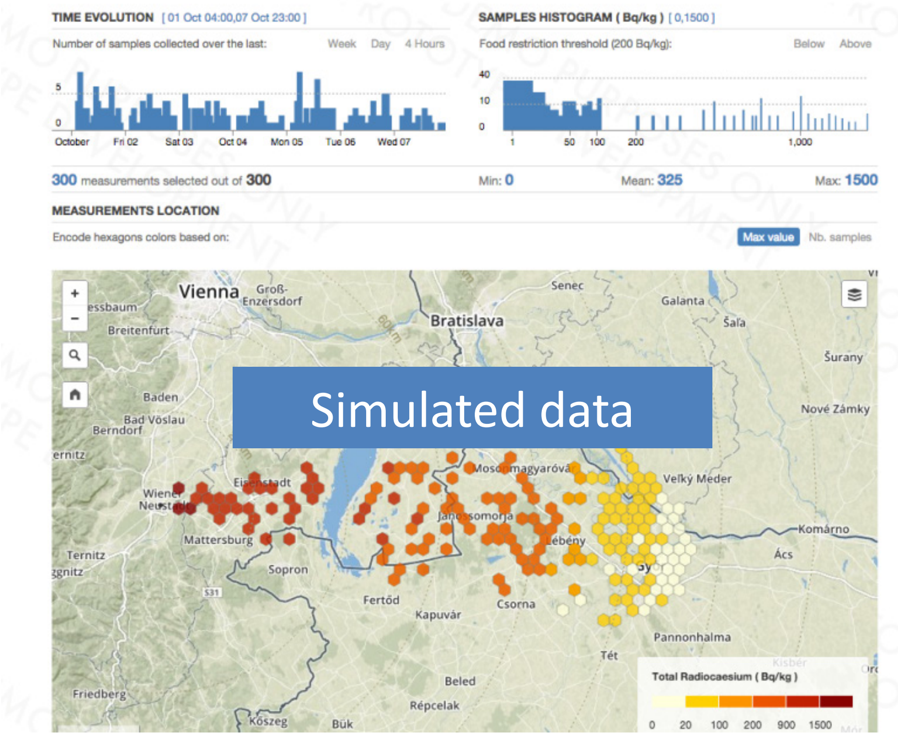

FIG. 1. An example of the interactive visualization component available in the FAO/IAEA on-line information system, showing radioactivity concentrations in food samples (this example is based on simulated data).

This system will create a virtual environment for collaborative interaction in and between Member States, and with FAO/IAEA and IAEA staff. As well as being a tool for enhanced information exchange and decision making on food or planting restrictions, it can be used to assess nuclear emergency situations in food and agriculture, as stipulated by the IAEA's mandate.

The prototype system can be accessed as an application on smartphones (Fig. 2). It can be used in routine monitoring as well as in an emergency. Promoting the routine use of such a system ensures that it will be maintained and developed in line with best practices and that users will not require specialist training should they be faced with an emergency — the system could be implemented at a moment's notice.

The level of confidentiality of the data is set by the user, e.g. in the affected country. It is envisaged to have two parallel platforms: (1) a decision making platform, which is now being developed; and (2) a public platform with static and non-confidential information, at the geographical scale agreed with the competent authorities. The system is stand-alone but designed to be able to transfer data with IAEA emergency response tools using established IRIX protocols. The system is open source and cloud based, including the mapping component.

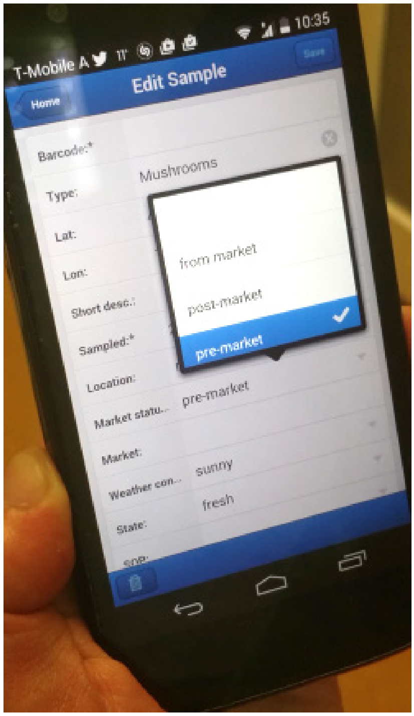

FIG. 2. Example of the interface of the FAO/IAEA on-line information system for food sample description, registering sample attributes via mobile devices (automatic georeferencing).

4. FOOD STANDARDS AND GUIDANCE

The Joint FAO/IAEA Division also develops and helps in the implementation of normative standards and guidance related to radioactivity in food. It participates in the Codex Alimentarius Commission and the Codex Committee on Contaminants in Food. The Codex is the international standard setting organization for food safety and it has guideline levels for radionuclides in food in international trade. The IAEA is also a standard setting organization, with several committees that develop international standards related to radiation safety. The Joint FAO/IAEA Division has been instrumental in developing and promulgating these standards, e.g. working with the IAEA, World Health Organization and the secretariats of both the Codex Committee on Contaminants in Food and the IAEA Radiation Safety Standards

Committee (RASSC) to develop guidance on developing criteria for radionuclide activity concentrations for food and drinking water. This guidance was recently published as IAEA-TECDOC-1788[1], which is consistent with both Codex and IAEA standards.

IAEA-TECDOC-1788 provides an overview and explanation of the different international standards relating to radionuclides in food and drinking water and the circumstances in which they are intended to be used, with particular focus on an existing (post-accident) exposure situation. It emphasizes that 1 mSv/year is the appropriate dose criteria for food because this is specified in the IAEA Basic Safety Standards in relation to existing exposure situations. The document includes a framework to help countries develop activity concentration levels for use at the national level which are consistent with the 1 mSv/year dose criteria for an existing exposure situation. This framework is aligned with the method used to develop the Codex Guideline levels for radionuclides in food intended for international trade.

5. CONCLUSION

Two current initiatives on radionuclides in food and agriculture are highlighted to illustrate the range of activities undertaken by the Joint FAO/IAEA Division. Both were undertaken in response to requests from Member States. One relates to a collaborative research project to develop an electronic support system, focusing on radioactivity in agriculture. The other relates to the development and production of normative standards and guidelines in support of actions to control radioactivity in food. Capabilities in this area, in combination with the support given and actions taken in the aftermath of the Fukushima Daiichi accident, indicate the capacity of the Joint FAO/IAEA Division. This growing capacity is essential to further support Member States in the development of their contingency planning and their preparedness and response initiatives related to nuclear emergencies affecting food and agriculture.

The Joint FAO/IAEA Division specializes in nuclear sciences related to food and agriculture. It has a range of experts from different radiation and agricultural backgrounds. In collaboration with experts from Member States, and from both the FAO and IAEA, the Joint Division is uniquely placed to provide assistance and technical support in relation to radionuclides in food and agriculture.

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AGRICULTURE LAND AND WATER

(Technical Session 1)

Chairperson

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DYNAMICS OF RADIOACTIVE CAESIUM BEHAVIOUR IN THE AGRO-ENVIRONMENT

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Abstract

Radioactive caesium (Cs: ^{134}Cs and ^{137}Cs) concentrations in soil are a key factor to determine the needs of decontamination and prohibition of crop cultivation. The paper reports on the changes of radioactive Cs concentrations in farmland soils over the five years since the accident and the factors controlling their rates of decrease. Considering the use of land for crop cultivation, radioactive Cs concentrations in the plough layer (0–15 cm) were evaluated. Analyses of a spatial distribution map of radioactive Cs based on the soil survey from October 2011 to February 2012 showed that 5900 ha (6%) of paddy fields and 3000 ha (5%) of upland, orchard and pasture fields exceeded 5000 Bq/kg in Fukushima. The soil survey from 2011 to 2015 on the same fields revealed that rates of decrease for radioactive Cs concentrations in farmland soils were generally comparable to the decrease by physical decay, but in some fields, the rates were faster than those expected from physical decay constant. Based on long term soil monitoring from 1954 to 2000 for the concentration of ^{137}Cs derived from atmospheric nuclear weapons tests, the effective half-lives of ^{137}Cs in the plough layers of paddy and upland fields were estimated to range from 9 to 24 and 8 to 26 years, respectively. These data suggest that radioactive Cs was lost from plough layers faster than the rates expected from physical decay, possibly by downward migration, surface runoff, or removal through plant uptake. The radiocaesium interception potential (RIP) of 925 farmland soils taken from Fukushima and surrounding areas was investigated. The RIP values were in the range from 73 to 12 700 mmol/kg and tended to be lower for volcanic ash soil, Andosols. Monitoring surveys of paddy fields and other agricultural fields revealed that radioactive Cs tended to be lost from farmlands at rates of less than a few per cent per year of the soil radioactive Cs inventory.

1. INTRODUCTION

Radiocaesium concentration in soil is a key factor to determine the needs of decontamination and prohibition of crop cultivation. Since radiocaesium is mainly fixed by clay minerals in soils, the long half-life of ^{137}Cs means it tends to remain in soil for a long time. However, loss of radiocaesium bearing soil particles as a result of erosion may not be negligible depending on the land use. Although there is only a small fraction of total radiocaesium in soils, part of radiocaesium can be released from soil to soil solution and becomes a source of radiocaesium that can be absorbed by crops. In the paper, the changes of radiocaesium concentration in farmland soils during a five year period after the accident, as well as the factors controlling rates of decrease of radioactivity, are investigated.

2. CHANGES IN RADIOCAESIUM CONCENTRATION OF FARMLAND SOILS FOR FIVE YEARS

Radiocaesium concentrations in the plough layer (0–15 cm) of farmlands were investigated. Analyses of a spatial distribution map of radiocaesium based on a soil survey from October 2011 to February 2012 showed that 5900 ha (6%) of paddy fields and 3000 ha (5%) of upland, orchard and pasture fields exceeded 5000 Bq/kg in Fukushima [1].

A soil survey from 2011 to 2015 on the same fields revealed that rates of decrease for radiocaesium concentrations in farmland soils were generally comparable to the decrease by physical decay, but in some fields, rates were faster than those expected from physical decay constant [2]. Based on long term soil monitoring from 1958 to 1993 for the concentration of ^{137}Cs derived from atmospheric nuclear weapons tests, the effective half-lives of ^{137}Cs in the plough layers of paddy and upland fields were estimated to range from 9 to 24 and 8 to 26 years, respectively [3]. These data suggest that radiocaesium was lost from plough layers faster than the rates expected from physical decay possibly by downward migration and surface runoff.

3. LOSS OF RADIOCAESIUM FROM PADDY FIELDS

Loss of radiocaesium bearing soil particles through water and wind erosion and input of radiocaesium through atmospheric deposition and irrigation water can cause fluctuation of radiocaesium concentration in soil from a long term view point. In order to determine the mass balance of radiocaesium in paddy fields, we took irrigation water, atmospheric deposition, surface and tile drainage, and soil samples at four paddy fields in Fukushima. A membrane filter with a pore size of 0.025 µm was used to separate the suspended solid and filtrate. Distribution coefficient (K_d) was calculated by dividing radiocaesium concentration in suspended solid by that in filtrate. In general, radiocaesium was lost from paddy fields at rates of less than a few per cent per year of the soil radiocaesium inventory (Table 1). However, in some paddy fields of low radiocaesium concentration in soils, radiocaesium input exceeded its output.

TABLE 1. MASS BALANCE OF RADIOCAESIUM IN DIFFERENT PADDY FIELDS IN FUKUSHIMA

Reference	Cropping Year	Radiocesium inventory	Radiocesium balance/inventory
		kBq/m^2	%
Taniyama I et al [4]			
	2011	589	-2.96
Yoshikawa S et al [5]			
	2012	10^3 to 10^4	-0.40
	2012		+0.07
	2012		-0.48
Onda Y et al [6]			
	2012	308	-0.14
	2012	25	-1.04
	2012	323	+0.093
	2012	342	+0.13
	2012	61	-0.002
Yoshikawa S et al [5]			
	2013	10^3 to 10^4	-0.060
	2013		-0.97
	2013		-2.48
Tsuruta R et al [7]			
	2014	210	+0.24
	2014	210	+0.16
Nakajima K et al [8]			
	2015	208†	+0.093
	2015	208†	-0.022
Mean ± SD			-0.52 ± 0.98

†Calculated/estimated values

The K_d values ranged from 10^2 to 10^6 L kg^{-1} and correlated with the radiocaesium interception potential (RIP), indicating the importance of RIP in predicting radiocaesium concentrations dissolved from soil (Eguchi et al., unpublished data).

4. RADIOCAESIUM INTERCEPTION POTENTIAL OF FARMLAND SOILS

The capacity and selectivity of soils for radiocaesium sorption also controls long term changes of radiocaesium concentration in soils, and are evaluated by the parameter called RIP. We investigated the RIP of 925 farmland soils taken from Fukushima and surrounding areas (Fig. 1). The RIP values were in the range from 73 to 12 700 mmol/kg and tended to be lower for volcanic ash soil, Andosols. When soils were categorized by mineral composition, the RIP of soils with micaceous minerals were significantly higher than those without crystalline clay minerals [9]. Since RIP is closely related with transfer factor (TF, the ratio: specific radioactive Cs activity in the plant tissue (e.g. brown rice) / specific radioactive Cs activity in the crop-soil) it is thought that plant availability of radiocaesium can be predicted using RIP values as one of the parameters [10]. We successfully predicted the TF of brown rice by modifying the Absalom model [11] using the RIP and potassium fertilizer application rate as input parameters [12].

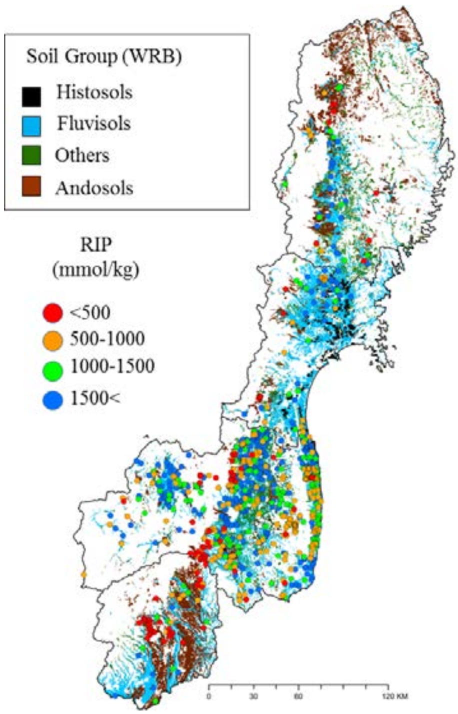

FIG. 1. Radiocaesium interception potential map plotted on the soil classification map (courtesy of Yamaguchi et al. [9]).

5. CONCLUSION

The RIP distribution map in combination with the soil radiocaesium concentration map gives fundamental information to evaluate the long term behaviour of radiocaesium in farmland soils. Especially in paddy fields, the loss of radiocaesium as a suspended solid likely caused shorter effective half-lives in soil than that expected from physical decay. However, five year monitoring was not sufficient to evaluate the controlling factor determining effective half-lives of radiocaesium in farmland soils. Continuous monitoring of farmland soils is required.

ACKNOWLEDGEMENT

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NATIONAL EXPERIENCE IN REMEDIATION OF CONTAMINATED FARMLANDS AFTER THE CHERNOBYL ACCIDENT

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Abstract

A wide range of effective countermeasures have been developed and applied to agricultural production in areas contaminated by the Chernobyl accident. Current and future needs for the remediation of affected areas are presented. In spite of the improvement of the radiation situation 30 years after the Chernobyl accident, a whole complex of problems connected with the protection of the population and rehabilitation of the lands still needs to be solved in the contaminated areas of Ukraine: 1003 settlements in Ukraine (26 700 km^2), where over 650 000 people live, are assigned to the zones of the radioactive contamination; the average annual effective doses for the population exceed 1 mSv in 25−26 settlements; in the part of the radioactively contaminated area it is impossible to permit the production of agricultural products which comply with radiation and hygiene standards without countermeasures. Thus, at the present time the measures aimed at the radiation protection of the population are the most important of the Chernobyl tasks. However, in recent years the protective measures aimed at reducing the radioactive contamination of products and the decrease of the doses for the population are not carried out according to the Law of Ukraine.

1. INTRODUCTION

The accident at Chernobyl was the largest radiation catastrophe in history and resulted in radioactive contamination of all European countries. Primarily, the Chernobyl accident had a negative impact on the rural population and agricultural production of the three most affected countries: the Republic of Belarus, Russian Federation and Ukraine. More than 150 000 km^2 of these three countries have been assigned to various zones of radioactive contamination. In general, 70% of released caesium and almost all ^{90}Sr and transuranic elements were deposited in these three countries. About one third of the contaminated territory was agricultural land. This extensive contamination of agricultural and semi-natural land had a significant effect on humans via contaminated food consumption. Over time, the impact of forest ecosystems (accounting for about a third of the contaminated area) on the intake of radionuclides by humans has increased [1].

The population was resettled from the most contaminated areas (6200 km^2 in Belarus (Ministry for Emergency Situations of the Republic of Belarus, 1994), 193 km^2 in the Russian Federation, and 4200 km^2 in Ukraine, including 2000 km^2 outside the Chernobyl Exclusion Zone) [2]. Also, traditional economic activity was stopped or largely limited in these territories.

2. THE EARLY PHASE OF THE CHERNOBYL ACCIDENT

In the early phase, ^{131}I was the main contributor to the internal dose through the pasture–cow–milk pathway. In late April/early May 1986, in Ukraine dairy cows were already grazing outdoors and there were significant levels of the activity concentration of ^{131}I in cow's milk exceeding acceptable levels, which ranged from a few hundred to a few tens of thousands Bq/L. The activity concentration of ^{131}I in milk decreased with an effective half-life of 4–5 days owing to its short physical half-life and the processes that removed it from pasture grass.

In the former USSR, including at the time of the Chernobyl accident, the food production system could be divided into two groups: large collective farms and small private farms. Collective farms routinely used land rotation combined with ploughing and fertilization to improve productivity. Traditionally, small private farms had one or several cows producing milk, mainly for personal consumption.

Radiation monitoring of the agricultural production contamination at large milk plants and in collective farms was arranged in 1–2 weeks after of the accident had occurred [1]:

- The urban population was mainly protected against the consumption of radioactive contaminated agricultural products, especially milk, through the distribution network (foodstuffs were delivered from clean regions).
- The rural population that had cows in private farms was not informed about the contamination of milk with ^{131}I, resulting in high doses to the thyroid gland and increase of thyroid cancer morbidity in children after the accident.

In the first few days after the accident, countermeasures were largely directed towards collective milk and few private farmers were involved. Information on countermeasures for milk was confined to managers and local authorities and was not distributed to the private farming system of the rural population. This resulted in limited application of the countermeasures with some delay, especially in rural settlements for privately produced milk, resulting in low effectiveness in some areas [1, 2].

Due to the feeding of animals with ‘clean’ fodder the ^{137}Cs content in cattle meat would reduce to permissible levels 1–2 months after the beginning of the countermeasure implementation. However, this countermeasure was not in widespread use at this stage, partly due to a lack of uncontaminated feed at this early time in the growing season (there was no additional reserve of clean fodder) [1, 2].

In order to decrease the internal radiation doses of the population, the first temporary permissible levels were approved by the USSR Ministry of Health only on 6 May 1986. Before the Chernobyl accident there were no permissible levels (PLs) for radionuclides in foodstuffs in the USSR. After the Chernobyl accident non-emergency PLs were accepted only 11 years after the accident. In Japan they were accepted after 1 year. Current non-emergency national PLs for foodstuffs, drinking water and wood in Belarus, the Russian Federation and Ukraine are comparable and all of them are substantially lower than the EU maximum PLs (except for dried wild berries and mushrooms) [1].

3. THE LATE PHASE OF THE CHERNOBYL ACCIDENT

Since the accident, the contamination with ^{137}Cs of agricultural products has decreased by factors of tens and hundreds due to fixing of the different soils and application of countermeasures, but the content of radiocaesium in *non-wood forest products* (mushrooms, berries, meat of wild animals) is several times greater than it was earlier [1].

Countermeasures were most intensively applied between 1987 and 1992 and encompassed numerous agrotechnical (radical or surface improvement of soils) and agrochemical (liming, application of mineral fertilizers) countermeasures [3, 4]. Recommendations on the application of these countermeasures have been summarized in IAEA Technical Reports Series No. 363, Guidelines for Agricultural Countermeasures Following an Accidental Release of Radionuclides (1994). The effectiveness and practicability of countermeasures, their costs and the resources required vary considerably depending on local farming practices and time passed after the accident, site specific environmental conditions, agricultural production management, lifestyle and dietary habits [1–5].

In the settlements of the northern regions of Ukraine [6], where the average dose is more than 1 mSv/a, the main contribution to the total dose is internal exposure to radiocaesium due to the consumption of milk and non-wood forest products contaminated with ^{137}Cs (Fig. 1). At this point, there are about ten settlements where the specific activity of ^{137}Cs in milk and cattle meat is always 3–4 times greater than PL-2006 standards now. Also, there are 50 settlements where the content of radiocaesium in milk may exceed the permissible levels [7]. The reason for such high levels of ^{137}Cs in plants and animal products is abnormally high bioavailability of the caesium on peat soils with a relatively low contamination density of the soil with ^{137}Cs

(about 100 kBq/m^2). During 2015, the highest average values of the ^{137}Cs content in milk were recorded in the Perehodychi village of Rokytne district (870 Bq/L, in May). Beside the waterlogged peats, abnormally high bioavailability of radiocaesium that slowly changes in time is also known to be present in Arctic and Alpine ecosystems due to the low rate of decay of soil organic matter at high moisture content and low temperature [1].

According to the Law, only these residential settlements should be designated as radioactively contaminated areas, and protective measures to reduce radiation exposure to the population must be carried out in these settlements. In these critical settlements, where the average annual effective dose is higher than 1 mSv, internal exposure is caused mainly by the consumption of local milk. The application of protective measures/countermeasures such as the radical improvement (creating highly productive artificial pastures) of fields or the use of a special sorbent for cows (ferrocyn) with a reduction factor (radiological efficiency) of 3 allows the ^{137}Cs content in milk to be reduced below the permissible level (100 Bq/L) and the dose of radiation exposure below 1 mSv/a in nearly all settlements. Unfortunately, since 2009 the protective measures to reduce radiation exposure to the population have not been applied in Ukraine [1, 2].

During the post-accident period, the radiation situation in the area radioactively contaminated improved significantly because of the radioactive decay of radionuclides, application of countermeasures and autorehabilitation processes. In Belarus, the application of the countermeasures made it possible to reduce the number of settlements which registered milk contaminated with ^{137}Cs and ^{90}Sr above PLs in private farms by several orders of magnitude. Also, the latter made it possible to reduce levels of radionuclide content in products in general [1].

Since in Ukraine the main contribution to the dose value is provided by the internal radiation exposure, at the present time the use of protective measures in agriculture (radical improvement of grassland and application of ferrocyn to cows) allows people to obtain products with radionuclide content below PL, and to decrease the average annual effective dose for the population to the level below 1 mSv in all settlements of Ukraine [1, 8–10]. IAEA Technical Cooperation projects with Belarus, the Russian Federation and Ukraine resulted in the ReSCA (Remediation Strategies after the Chernobyl Accident) programme to provide assistance to decision makers and to facilitate selection of an optimized remediation strategy in rural settlements [9].

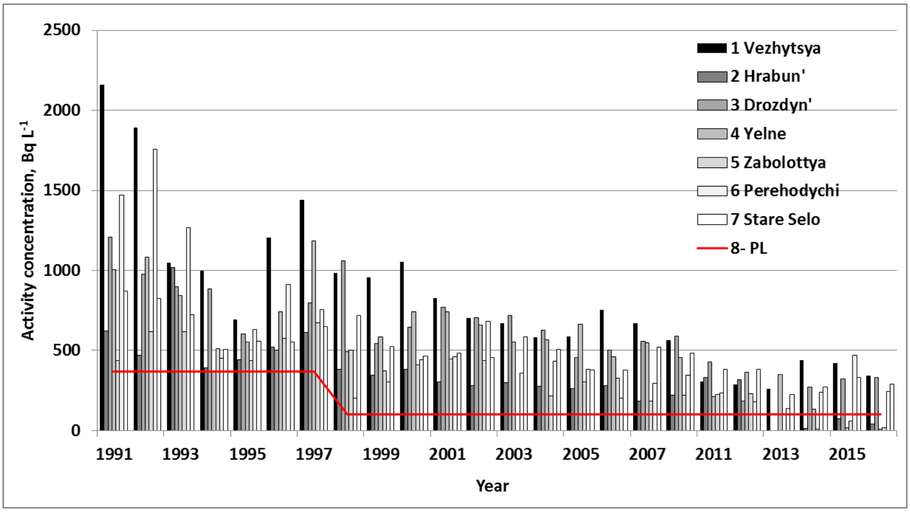

FIG. 1. The dynamics of average milk contamination by ^{137}Cs produced on private farms of the most critical settlements in Ukraine during the grazing period (arithmetic mean n > 20) and PL.

4. CONCLUSION

Over the last thirty years a wide range of effective countermeasures have been developed and applied to agricultural production in areas contaminated by the Chernobyl accident. Their implementation on more than 4.5 billion hectares of agricultural land has made it possible to continue to produce food in these areas, substantially reduced the number of products with radionuclide activity concentrations above PLs and provided substantial reduction of doses to the population. Thus, the total averted doses for the three most affected countries amounted to 12 000−19 000, or 30%−40% of the internal collective dose that would be received without the use of countermeasures [1, 3].

According to the recommendations of the IAEA Chernobyl Forum [4]: “Unique experience of countermeasure application after the Chernobyl accident should be carefully documented and used for preparation of international and national guidance for authorities and experts responsible for radiation protection of the public and the environment”.

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DEVELOPMENT OF PHYSICAL TOPSOIL REMOVAL TECHNIQUES AND MACHINES FOR FARMLAND DECONTAMINATION

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Abstract

After the Tokyo Electric Power Company (TEPCO) Fukushima Daiichi nuclear power plant accident, radioactive material fell over a wide area of farmland in Fukushima Prefecture. Most of this material was concentrated in the topsoil of the farmland, which was several centimetres thick. Therefore, to decontaminate the farmland, the topsoil was scraped off. Currently, conventional construction machines such as power shovels and dump trailers are being used for this purpose. However, these machines operate very slowly and have low efficiency. A new machine has been developed to improve the efficiency of the topsoil removal work. An agricultural tractor mounted type machine was developed with a working width of 2.2 m. Field tests were conducted by attaching the developed machine to a semi-crawler-type tractor (engine power: 77 kW). As a result, the working speed was 0.2 m/s (0.7 km/h) and work efficiency was ~0.8 h/10 a when the maximum scraping depth was set to 5 cm. The working speed was 0.1 m/s (0.4 km/h) and work efficiency was ~1.4 h/10 a when the maximum scraping depth was set to 8 cm. In this case, the error associated with setting the scraping depth was approximately the depth setting minus 1 cm. However, the scraping performance was affected by various conditions of the topsoil, such as the degree of surface undulation, hardness, moisture, and presence of mowed weeds. Before the field test, the radiation dose rate at a height of 1 cm from the ground was 0.23 μSv/h (0.78 μSv/h at a height of 1m); the measured value after scraping to a depth of 5 cm was 0.08 μSv/h (~65% reduction). The developed machine was commercialized in 2015, and 10 units were introduced in Kawamata town and Iitate-village

in Fukushima Prefecture. According to local reports, the work efficiency of these machines was almost the same as that in the field test results, and the work efficiency of topsoil removal was improved relative to those of a power shovel and skimmer, which is a self-propelled type of topsoil scraping and scooping machine.

1. INTRODUCTION

After the accident at the Fukushima Daiichi nuclear power plant, radioactive material fell over a wide area of farmland in Fukushima Prefecture. Most of this material was concentrated in the topsoil of the farmland, which was several centimetres thick [1]. Therefore, to decontaminate the farmland, the topsoil was scraped off.

Currently, conventional construction machines such as power shovels and dump trailers are being used for this purpose. However, these machines operate very slowly and with low efficiency. Therefore, we have developed a new machine to improve the efficiency of the topsoil removal work.

2. OUTLINE OF THE DEVELOPED MACHINE

We developed an agricultural tractor mounted machine with a working width of 2.2 m. Table 1 and Fig. 1 show the specifications and an overview, respectively, of the developed machine. The standard working speed of the machine is approximately 0.1–0.2 m/s, which comprises the fine low speed traveling mode of the mounted tractor with an engine output greater than 64 kW (85 PS).

The machine consisted of a topsoil cutting unit with 48 arranged L-shaped soil cutting blades, a transporting vertical auger for removed soil, and two suppression rollers attached to the front and rear bottom of topsoil cutting unit [2].

TABLE 1. SPECIFICATIONS OF THE MACHINE

Length, mm	1274
Width, mm	2512
Height, mm	1157
Weight, kg	798
Working width, mm	2200
Scraping depth, cm	0～8
Cutting blade, set	48 (L-shaped)
Width of soil discharge, mm	770
Working speed, m/s (km/h)	0.1～0.2 (0.36～0.72)
Proper engine output of the tractor, kW(PS)	>64 (85)
Tractor mounting unit type	Standard 3 point link, Direct attach type 2 (JIS)

3. PERFORMANCE TESTS OF THE DEVELOPED MACHINE

In order to clarify the power requirements of the machine, a power take off (PTO) test was conducted in the paddy field after harvesting rice from the nearby IAM farm (soil texture: silty clay SiC, moisture content: 45.9%). The test results are shown in Table 2.

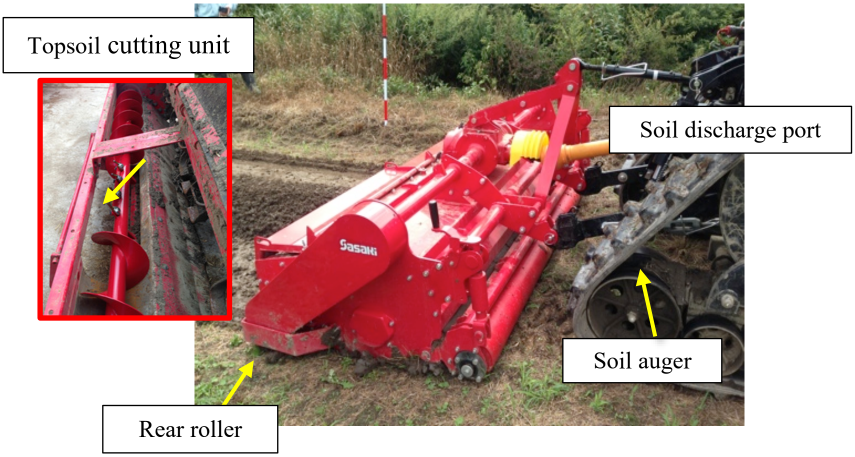

FIG. 1. Proposed topsoil removal machine.

TABLE 2. REQUIRED POWER TEST RESULTS

Scraping depth setting (cm)	Scraping depth actual (cm)	Working speed (m/s)	PTO torque (Nm)	PTO revolution (rev./min)	PTO power requirement
3	2.3±0.8	0.19	516.5	431.5	23.3
5	4.2±0.8	0.12	656.5	435.0	29.9
7	The test was discontinued because the scraped soil clogged the outlet of the soil discharge port.				

Field tests were conducted by attaching the machine to a semi-crawler type tractor (engine power: 77 kW). The resultant working speed was 0.2 m/s (0.7 km/h), and the work efficiency was 0.8 h/10 a when the maximum scraping depth was set to 5 cm. Furthermore, the working speed was 0.1 m/s (0.4 km/h) and the work efficiency was 1.4 h/10 a when the maximum scraping depth was set to 8 cm. In this case, the error of the scraping depth was approximately equal to the depth setting minus 1 cm. However, the scraping performance was affected by various conditions of the topsoil, such as the surface undulation, hardness, moisture, and presence of weeds. Before the field test was conducted, the radiation dose rate was measured at a height of 1 cm from the ground and found to have a value of 0.23 µSv/h (0.78 µSv/h at a height of 1 m); the measured value after scraping to a depth of 5 cm was 0.08 µSv/h (65% reduction).

4. CURRENT SITUATION AND FUTURE PLANS

The machine was commercialized in 2015, and 10 units were introduced into the town of Kawamata-cho and the Iitate-village in Fukushima Prefecture. According to local reports, the work efficiency of these machines was found to be nearly identical to the field test results (Table 3). Additionally, the work efficiency of topsoil removal was improved over those of a power shovel or a skimmer, which are self-propelled types of topsoil scraping and scooping machines.

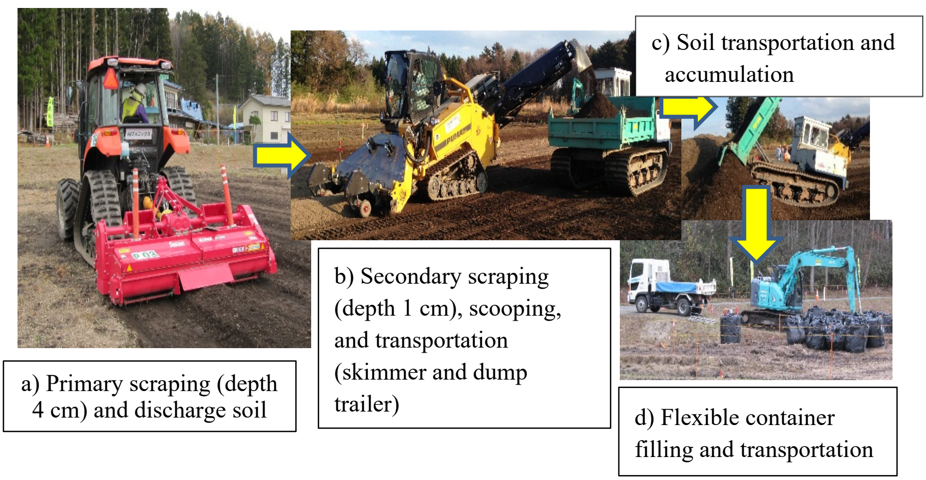

FIG. 2. A working example in an Iitate village decontamination work area (machine and a skimmer used jointly).

TABLE 3. EXAMPLES OF DECONTAMINATION WORK IN IITATE VILLAGE*

Place		Location: Fukushima-ken, Souma-gun, Iitate-village								
Methods, machines		Period (2015)	Workers (person /day)	Working hours (h/day)	Working days (day)	Total area (ha)	Total hours (h)	Efficiency (h/10a)		
								Ave.	Max.	Min.
Individual Work										
Skimmer A	Scrape/5 cm + Transport	5/13～9/24	2～3	6	28.5	3.79	171	4.5	2.1	20.0
Skimmer B	Scrape/5 cm + Transport	5/26～8/20	2～3	6	14.5	2.05	87	4.3	2.7	8.8
Cooperation Work (a+b or a+c)										
a) Developed	Scrape/4 cm	5/18～6/8	1～2	6	17.0	6.14	102	1.7	1.0	2.1
b) Skimmer A	Scrape/1 cm + Transport	5/21～6/13	3	6	15.0	3.89	90	2.3	1.7	3.3
c) Skimmer A	Scrape/1 cm + Transport	5/26～6/13	3	6	8.0	2.13	48	2.3	1.7	3.0

Note: * Calculated from the actual work data recorded and provided by the local office.

5. CONCLUSION

In conclusion, the developed topsoil scraping machine has been commercialized, and generally performs well. However, it is difficult to use under wet soil conditions, and struggles to perform conventional rotary tilling work, making it necessary to consider the soil moisture content and the presence of weeds or stones. It was confirmed that the machine contributed to improvements in the efficiency of topsoil scraping in the working fields of the site.

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The production of prototypes and execution of field tests were greatly assisted by the cooperation of Kubota Co. and Sasaki Cooperation, Inc. Additionally, field testing was facilitated by the cooperation of Mr Yuzo Mampuku, who is in charge of decontamination at Iitate village Recovery Measures Department (on secondment from the Central Region Agricultural Research Center, NARO); NARO's researchers; officers of Iitate village and the Research Management Office of the Agriculture, Forestry and Fisheries Research Council in the Ministry of Agriculture, Forestry and Fisheries; and many others.

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INTEGRATED APPROACHES FOR A BETTER UNDERSTANDING AND MODELLING OF RADIONUCLIDE TRANSFERS ALONG THE SOIL-SOIL SOLUTION - PLANT CONTINUUM

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Abstract

The objectives of the investigation were to develop more realistic approaches, combining modelling and experimental tools for enhancement of both short and long term prognoses of contamination transfer as well as for supporting potential applications (safe food/phytoremediation in relation to the DEMETERRES project). To achieve these goals, in-depth investigations were conducted of mechanisms at the soil/root interface and developed in parallel with specific mechanistic modelling. These approaches are currently applied to caesium (Cs) in the soil/soil solution/plant continuum, with experiments on various soils and plants to acquire parameters and/or test the validity of the models. Different modelling approaches are compared: simple radioecological models with semi-mechanistic and generic mechanistic models for Cs sorption. For the latter, a new generic approach was used which combines surface complexation and cation exchange and only two types of exchange sites, taking into account the cation competitions, as well as the effect of ionic strength and pH. Parametrization for Cs and the tested soil was studied in closed reactors. Results were also used to define two contrasting contamination conditions focusing on the two types of sorption sites. In addition, stirred flows through reactors were used to acquire kinetic parameters of Cs/soil interaction (E-K model). Plant uptake of Cs proceeds via some of the transporters dedicated to potassium (K) and is thus subjected to K homeostasis. The uptake of Cs is assessed by transfer factor (TF) model or by a Michealis-Menten model type. These are outputs partly acquired in the French DEMETERRES project that aims at developing methods of agricultural soil remediation/management, in particular green technologies. Experiments focused on rhizosphere issues and its potential effect on the soil capacity to feed the soil solution and its kinetics were launched as a first set for model validation. Two tools were deployed: (1) diffusive gradients in thin films (DGTs) devices as passive samplers (surrogate of root uptake process); and (2) the rhizotest tool, used with ryegrass and the soil contaminated with ^{137}Cs. This design allows the contact of a large volume of roots with a small volume of soil and thus maximizes the root effect.

1. INTRODUCTION

Operational tools for soil to plant radionuclide transfer assessment still suffer from great uncertainties due to the complexity of processes at the root interface (e.g. desorption from solid phase, rooting, exudation, uptake), and their aggregation within simple radioecological parameters with highly variable generic values (K_d, root transfer factors). Numerous models (based on mechanistic, semi-mechanistic, empirical approaches) describing some parts of the soil–soil–solution–plant continuum exist, with different complexities and fit, most of the time, specific objectives. Usually, parametrization of these models is conducted through short term experiments in laboratory conditions and often with artificially contaminated substrates. Yet, these models may be used to conduct short but also long term assessment of the behaviour of contamination, for example in ecological risk assessment of existing nuclear facilities.

Our objectives are thus to develop more realistic approaches, combining modelling and experimental tools for enhancement of both short and long term predictions of contamination transfer as well as for supporting potential applications (e.g. safe food/phytoremediation as developed in the French DEMETERRES project, which aims at developing methods of agricultural soil remediation/management, green technologies in particular (see the abstract from A. Vavasseur in the Plant and Crops Products session). Our integrated approach combining mechanistic description of processes, modelling issues and use of experimental tools for validation is summarized in Fig. 1. These approaches are being used for Cs in the soil/soil solution/plant continuum, with experiments on various soil(s) and plant(s) to acquire parameters and/or test the validity of the models. In addition, numerous other experiments, although not in an integrated manner, had been conducted with other radionuclides (U, Se).

2. PROCESSES: HOW TO ASSESS AND MODEL THEM

As shown in Fig. 1, two sets of processes are to be assessed: those at the soil-solution interface, supposedly the limiting step in the transfer process, and those at the root interface, linked with plant physiology. Our objective is to establish the link between the two.

On the soil side, it is well known that part of the radionuclide inventory associated with the soil solid phase is not reversibly sorbed. A proportion of radionuclide inventory is strongly bound to the soil solid phase and is either not available or slowly available to the soil solution. For each radionuclide (or element) under consideration, it is necessary to determine the nature and affinities of sorption sites in order to predict the radionuclide inventory that may be released and therefore present in the soil solution during a certain time (bioavailability). The proportion of bioavailable radionuclide in soil solution at the root interface is the key to understanding further transfer to the plant and its evolution in time, or as a function of environmental parameters.

The current research aims to compare different modelling approaches to describe the soil–soil solution continuum. The simple equilibrium approach used in radioecological modelling (e.g. using the dissociation constant, *Kd*) is progressively substituted with an alternative model based on a combination of equilibrium and kinetic liquid/solid processes (the so called E–K model) that takes into account different pools (or reserves) of radionuclides in soil, ranked as a function of their availability. This approach is complemented by a more mechanistic method describing the different elementary reactions for each reactive component of the soil that play a major role in radionuclide sorption and desorption processes. This thermodynamic model is based on the concept of additivity of reactive components in soil. For this, we developed a new generic and efficient approach which combines surface complexation and cation exchange, considering cation competition, as well as the effects of ionic strength and pH [1].

In the models, soil solution is the compartment between and connecting soil and plant compartments. Understanding processes at the root interface (rhizosphere) is the key to correctly assess transfer and connect both compartments in models. At the soil–solution/root interface, soil–solution physico-chemical parameters may be considerably changed by root activity. Root activity (uptake, exudation) is due to the balance between sensing of environmental variables at the root interface (in particular, the concentration/flux of nutrients) and the tightly regulated physiology (i.e. the plant demand for growth with eventual feedback due to internal toxicity of elements). Two groups of interlinked variables should be assessed. The first group concerns rhizospheric processes (exudation of protons or organic acids, uptake) and their consequences on the release of radionuclides by the solid phase and its kinetics compared to bulk soil (bioavailability side). The second group of interlinked variables (plant side) concern the plant capacity for uptake due to transporters initially dedicated to nutrient uptake that change in nature, number and activities depending the environmental variables. The corresponding experimental approach consists of various in-depth investigations of these mechanisms at the soil/root interface. Such mechanisms are element-dependent, an investigation is necessary for each different radionuclide (^{75}Se, U, ^{137}Cs).

On the modelling side, we did not develop a specifically new model, but we parametrized existing ones and connected them with the soil/soil solution models. In particular, for Cs, plant uptake can be modelled by: (i) the linear equilibrium transfer factor model; or (ii) kinetic parameters (Km and Vm) from the Michaelis-Menten model which takes into account different plant physiologies (e.g. Cs uptake in low K or high K rhizospheric conditions); (iii) more mechanistic models such as Barber-Cushman (including Michaelis-Menten parameters but also the effect of depletion at the root surface), or the Terrestrial Biotic Ligand Model based on thermodynamic equilibrium modelling.

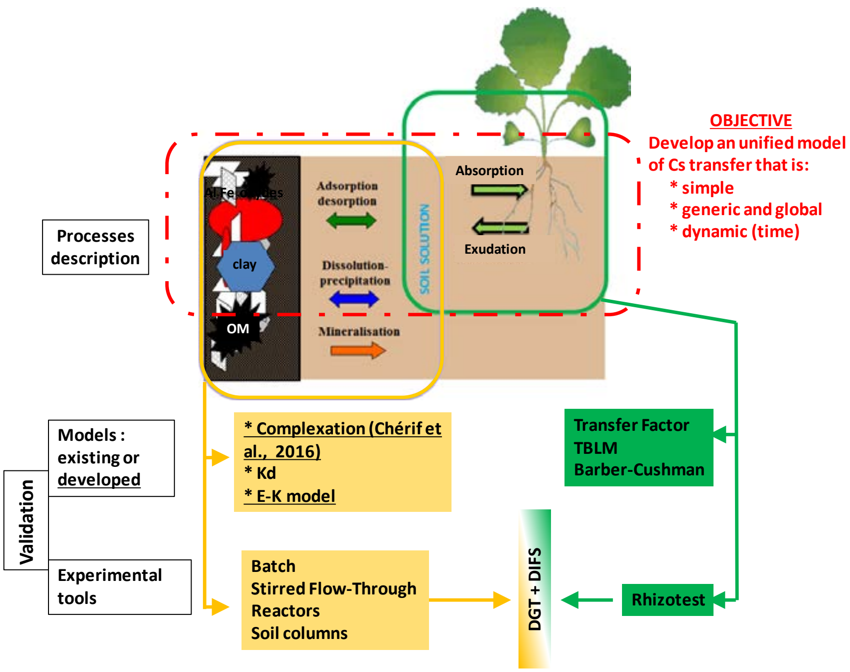

FIG. 1. Approach used for the global assessment of the soil–soil solution–plant continuum.

3. PARAMETRIZATION

Kd and TF values are taken from the IAEA database of radioecological parameters or may be measured (e.g. *Kd* on test soil) with dedicated experiments (batch for *Kd*, pot for TF). Experiments with stirred flow-through reactors were used to acquire kinetic parameters of radionuclides/soil interaction (E–K model) for different soils and conditions. Existing data were used to determine the set of parameters of the mechanistic thermodynamic model developed for Cs and clay.

Existing data are used to parametrize plant models and new acquisition of parameters is conducted only when needed. For example, plant Cs uptake issues are addressed in the DEMETERRES project, which can provide outputs such as K conditions or kinetic parameters for uptake used to parametrize plant transfer.

4. EXPERIMENTAL TOOLS FOR SOIL–PLANT CONNECTION STUDIES AND VALIDATION OF ASSOCIATED MODELS

Validation of process based approaches requires deployment of specific and 'simplified' laboratory experimental tools before testing in real cases (field experiments). We used (if possible in parallel) the following experimental devices:

(a) DGTs (Fig. 2, diffusive gradients in thin films), as passive samplers. They are used to provide a surrogate of the root uptake process, resulting in the depletion near the root surface. The same phenomenon occurs at the DGT surface which allows probing of how equilibria at the soil solid phase/solution interface respond to 'uptake';
(b) The rhizotest tool (Fig. 2), which brings into contact a small layer of soil with a root mat. It is a normalized biotest for bioavailability assessment of heavy metals in soils (ISO 16198 [2]). We use our own design as a means to boost the root effect on soil that is considered as homogeneous rhizospheric soil.

The experiments were conducted on Se U and Cs contaminated soil.

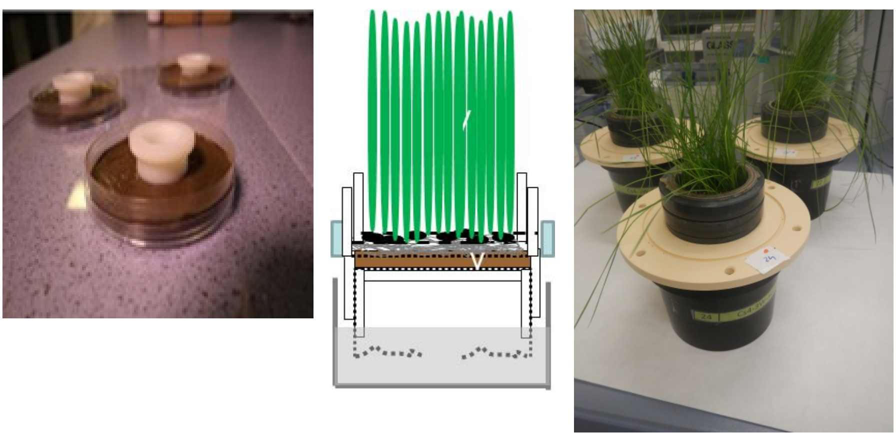

FIG. 2. Diffusive gradients in thin films (DGTs) deployment scheme of rhizostest and rhizotest with ryegrass.

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PLANTS AND CROP PRODUCTS

(Technical Session 2)

Chairperson

S. NIELEN
Joint FAO/IAEA Division of Nuclear Techniques in
Food and Agriculture

MITIGATION OF RADIOACTIVE CAESIUM TRANSFER FROM SOIL TO PLANTS

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Abstract

To mitigate the contamination from the Fukushima Daiichi nuclear power plant accident, many agricultural fields in Fukushima Prefecture were treated mainly by topsoil removal and potassium application. Both countermeasures sufficiently reduced the level of radiocaesium contamination in agricultural products. This paper describes the situation five years after the accident and discusses the remaining problems in the disaster area.

1. INTRODUCTION

As a result of the accident at the Tokyo Electric Power Company (TEPCO) Fukushima Daiichi nuclear power plant in March 2011, radiocaesium contaminated vast areas, including crop land. Even after a lapse of several years, farmers are still being asked to implement measures to reduce the uptake of radioactive materials into the crops grown on farmland. To mitigate the transfer of radioactive caesium from soil to plants, potassium fertilizer is being applied as the most effective method to reduce the uptake of radioactive caesium to the edible part of plants. In the case of food supply, the concentration of radioactive substances in food has been required since 2012 to be less than the standard value of 100 Bq/kg. Both the removal of radioactive caesium from fields and the suppression of its transfer rate from soil to plants by maintaining exchangeable potassium levels in soil throughout the growth stage have succeeded in reducing levels of radioactive caesium in food products. The contamination was limited to the very thin, but fertile, topsoil layer. However, removal of this contaminated soil and its replacement with uncontaminated (but less fertile) soil from the surrounding mountains has, in some instances, reduced the fertility of the fields and has also induced erosion. We have therefore attempted to develop methods to compensate for the loss of productivity. Planting forage grasses, for example, to increase soil fertility and also reduce topsoil erosion from the field. In addition, we are now seeking to regulate the long term effects of radioactive caesium contamination.

2. COUNTERMEASURES TO DEAL WITH THE ACCIDENT AT THE FUKUSHIMA DAIICHI NUCLEAR POWER PLANT

A literature survey of the effects of radiocaesium on paddy rice production revealed that there has been a very limited number of experiments on this issue (e.g. Refs [1, 2]). The maximum soil to plant transfer factor for radioactive caesium was identified as 0.1 for rice. In 2011, the temporary limit for radioactivity in major food products was set at 500 Bq/kg (it was reduced to 100 Bq/kg in 2012). Thus, if the soil radioactive caesium concentration is lower than 5000 Bq/kg, it is possible to grow rice that has less than 500 Bq/kg of radiocaesium without taking any countermeasures. Based on this use of a maximum soil to plant transfer factor, rice production was allowed in those areas with 5000 Bq/kg of radiocaesium or less in soil. Although this approach proved to be largely successful, it was not infallible and several areas where the radiocaesium level in soil was lower than 5000 Bq/kg produced brown rice with a radiocaesium content that exceeded 500 Bq/kg. Yonezawa and Mitsui [3] and Tsumura et al. [4] reported that potassium fertilization is the most effective countermeasure against radioactive caesium uptake by rice, but the number of actual field experiments was very small. From the analysis of those plant and soil data, it can be seen that soil exchangeable potassium content is critical in determining the transfer factor of radioactive caesium even under different field conditions and different soil types [5].

As mentioned earlier, in 2012 the limitation value for radioactive caesium in food was reduced to 100 Bq/kg. Therefore, additional applications of potassium fertilizer were used to help supress radiocaesium uptake by maintaining the soil exchangeable potassium level over 25 mg K_2O/100 g through the growth period (the soil radioactive caesium content was lower than 5000 Bq/kg). To meet this requirement for food to contain less than 100 Bq/kg of radiocaesium, farmers are required to apply additional potassium fertilizer before traditional fertilizer application. The appropriate amount of exchangeable potassium to apply to land was determined based on the potassium and transfer factor relationship not only for rice [5], but also upland crops [6–7]. It should be mentioned that the transfer factors of several upland crops (e.g. soybean and buckwheat) are about ten times higher than that of rice. The mechanism and effectiveness of these countermeasures are still being researched.

In those areas where the topsoil contamination level was over 5000 Bq/kg, 5 cm of topsoil removal is progressing. In Japan, topsoil removal is considered the best way to reduce the radiation exposure from soil and to reduce the migration of radioactive caesium from soil to plants. However, the decontamination of soil also brings several problems, such as soil erosion (there is a time gap between decontamination and the beginning of agricultural cultivation), weed invasion, and low fertility of the remediated soil (Fig. 1). As these decontaminated areas are intended for agricultural use within a few years, it is necessary to keep the fields ready for agriculture. It is therefore recommended that cover crops be introduced, and a labour saving management system is being studied.

Inspections were carried out in 2012 in Fukushima Prefecture to monitor bags of brown rice (30 kg). Since 2014, no bagged rice exceeded the 100 Bq/kg limitation value out of more than 10 million bags inspected. This indicates that the risk of exceeding the limitation value has reduced, and it was felt appropriate to re-evaluate the countermeasure of potassium application to mitigate radioactive caesium uptake into crops. At the end of five years, most of the affected fields (ca 6000 ha) have been decontaminated and are ready for cultivation. Farmers have started to cultivate the land while applying countermeasures and monitoring the fields. However, additional potassium application requires extra funding and greater labour by farmers, and there is also concern that the heavy application of potassium to the soil may have an adverse effect on the quality of plants and/or condition of the soil. A re-evaluation of the amount of additional potassium application to effectively suppress caesium uptake is in progress. This is because the levels of available caesium in soil has decreased due

FIG. 1. Soil erosion caused by heavy rains after decontamination (left) and weed invasion in the decontaminated field (right). (Photos courtesy of Dr Yoshino)

to the physical loss, e.g. by radioactive decay and the fixation of radioactive caesium into the soil, which is an ageing effect. Therefore, we are now attempting to reduce the level of exchangeable potassium that needs to be applied during the growth period from 25 mg K_2O/100 g to a lower and more suitable value, being careful to make sure that this does not result in crops that would exceed the limitation value for radioactivity in food. The amount of radioactive caesium in the soil, its transfer factor into the crop and the amount of exchangeable potassium in the soil are the major factors in determining the amount of radioactive caesium in the produce. Furthermore, several soil types seem to have higher/lower mitigation activity and it is necessary to clarify the mechanism through their physico-chemical (and/or biological) characteristics.

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PHYTO-MANAGEMENT OF CONTAMINATED LAND: SCIENCE, TECHNOLOGY AND CONTEXT

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Abstract

The accidents at the Chernobyl and Fukushima Daiichi nuclear power plants have raised questions about the accumulation of radionuclides in soils, the transfer in the food chain and the possibility of restricted land use in the foreseeable future. The paper summarizes what is generally understood about the application of agricultural countermeasures as a land management option to reduce the transfer of radionuclides in the food chain and to facilitate the return of affected soils to agricultural practices in the vicinity of the Fukushima Daiichi plant. It focuses on phyto-management approaches, evaluating their effectiveness and feasibility, considering radiological and technical criteria, and highlights the importance of considering societal aspects.

1. INTRODUCTION

Recovery projects such as land management based countermeasures help restore living conditions in areas affected by a nuclear accident, but may in turn have a large socioeconomic impact [1]. Apart from the reduction of ingestion dose and direct monetary cost, many more aspects determine the global feasibility of land management options and show the complexity of land management: practicability; environmental characteristics; indirect costs from side effects, e.g. loss of soil fertility in the case of deep ploughing; dose received during implementation of countermeasures; waste generated; social acceptability of the countermeasure itself and of products originating from contaminated land.

Land management options can be categorized into three types: physical; agrochemical; and plant based countermeasures, the latter being highlighted in the next section. Regarding physical countermeasures, in Japan, topsoil removal was considered as the most efficient countermeasure for agricultural ecosystems to rapidly reduce radiocaesium in soil (reported efficiency 75–97%). This approach, however, created a huge amount of waste. Ground shine dose was not always proportionally reduced, since small sized lands are surrounded by contaminated forests. Tillage, deep ploughing and skim and burial ploughing were applied both in the affected areas of Chernobyl and Fukushima. Tillage resulted in 2–4 fold reductions in transfer factors in the first year after the Chernobyl accident. Skim and burial ploughing resulted in 8 to 16 fold reductions. In Fukushima, reduction factors with deep ploughing were only 2 to 3 fold [2].

Potassium fertilization proved to be an effective agrochemical countermeasure to inhibit radiocaesium uptake by crops in the low intensity agriculture of the Chernobyl affected areas on sandy and organic soils, which often suffered from K depletion. In Fukushima, with its intensive agriculture, the K status of the soil was generally adequate and K fertilization was less effective in reducing Cs uptake. Addition of aluminosilicates reduced radiocaesium uptake by a factor of up to 2 in Chernobyl affected areas, where soils with a limited fixation capacity are prevalent. On the finer textured Fukushima soils, amendment with clay minerals or zeolites was barely effective [3].

2. PLANT BASED COUNTERMEASURES

Several plant based countermeasures were applied in the Chernobyl affected area [4]: selecting other varieties of the same crop (maximum dose reduction factor: 2–4); other comparable crops (2–3); green vegetables to cereals (5); arable land to cattle (10–100); cereals to edible industrial crops, e.g. oil seeds, sugar beet (>10); and cereals to non-food industrial crops, e.g. flax, energy crops (>10). Penrose [5] evaluated cultivar substitution as a remediation strategy. For *Brassica oleracea*, hybrid ryegrass, *Lolium perenne* and *L. multiflorum,* higher variation in concentration ratios than presented above were found for radiocaesium (up to 35, 14, 13, two fold) and strontium (up to 23, 4.4, 2.5, 2.9-fold). This may be due to the larger numbers of cultivars in these experiments (number ranged from 29 to 189). In Japan, Ohmori et al. [6] revealed a ten fold difference in radiocaesium uptake for 58 rice cultivars. Similar reduction was obtained for Azuki bean [7].

Transfer from food to feed production was also evaluated in Japan [8], considering that a 100 Bq/kg limit applies also for feed stuff.

Ukraine and Belarus, but also Japan, with significant parts of their territory affected by the respective nuclear accidents, may develop alternative land uses, like establishing non-food-crops (biofuel, fibre crops) on these contaminated lands. Vandenhove et al. [9] concluded that energy production from willow short rotation coppice (SRC) is a potential ecologically and economically sustainable option, but both aspects need to be evaluated thoroughly for the prevailing conditions. Cultivation and conversion are of no major radiological concern and end products are nominally free of contamination. The same conclusions hold for liquid biofuel except that the actual cost of liquid biofuel is significantly higher than that of fossil fuel [10]. The production of rapeseed and processing to edible rapeseed oil are profitable technologies and are practiced in, for example, Belarus and Japan, but not on contaminated land.

Socio-political perception of the end products from contaminated land affects system feasibility. No information could be found on the application at the industrial level of biofuel production and conversion technology on contaminated land in the Chernobyl affected territories. The potential for revitalization of the rural economy in Japan through the enhancement of local rapeseed production and conversion to edible oil was positively evaluated by Nonaka and Ono [11]. Also, non-soil-based land uses (greenhouses, aquaculture, possibly in combination with solar farms) may be considered an alternative land use option [12].

Phytoextraction, the removal of a contaminant from a substrate through the action of plants, is often presented as a feasible and ecological way to clean up among other contaminated soils [13], but is far from being an effective remediation option. Also, for radiocaesium contaminated land, far less than 1% (rather 0.01–0.1%) is removed on an annual basis [2, 14]. This indicates that it is difficult to remove radiocaesium from contaminated soil by means of phytoremediation. Additionally, the annual decrease in soil radiocaesium concentrations by physical decay is ~3%. Further, phytoextraction involves costs at different stages in the process with limited return on investment (land preparation, crop maintenance, waste treatment). Contaminated biomass needs to be harvested, transported and treated and this scheme of action will have to be repeated on a yearly basis for several years.

3. SOCIAL, ECONOMIC AND POLICY ASPECTS OF REMEDIATION

Post-accident recovery is a technically intensive issue involving scientific and societal uncertainties, differing risk perceptions, asymmetrically perceived risks and benefits, disagreement among experts and societal trust issues. The Chernobyl accident showed that acceptability of countermeasures, ethical and environmental considerations, requirements for public communication, spatial variation and the contrasting needs of people in urban, rural and industrial environments are important factors apart from radiological and feasibility criteria. The experience in Fukushima Prefecture has confirmed this. The aftermath of both accidents highlighted the benefits of involving stakeholders in recovery activities, from consultation and dialogue to remediation actions [1]. For both Chernobyl [15] and Fukushima Daiichi [1], consumption, processing and distribution of produce from affected areas declined after the accident due to the negative image associated with it, causing reduced revenues from agriculture and business, decline in certain types of production and closure of agricultural and industrial facilities. The overall feasibility of countermeasures is affected by the perception of the end-users related to the existence of the (faintest) presence of radionuclides in the end products even if not intended for human consumption (e.g. biofuel, fibre).

4. CONCLUSION

Lessons learned from the Chernobyl and Fukushima Daiichi accidents call for increased focus on post-accident recovery, in particular the legal and regulatory frameworks, criteria for residual radiation doses, and contamination levels and waste management strategies [1].

Continued effort is needed to identify sustainable ways to valorize the affected areas and revive the economic potential for the benefit of the community. Countermeasures must be sustainable and need to lead to profitable or self-sufficient production of produce with low radionuclide contamination. Also, the optimization of phyto-management options is possible, as for example in crop species selection for very low uptake and high yields. Alternative land uses are potential approaches to revitalize contaminated agricultural land but require more in-depth study at the radioecological, technological, economic and social levels. Non-soil (direct) based phyto-management approaches (greenhouses — soil or aquaculture) are high potential new venues for the recovery of contaminated land.

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DEMETERRES: A COLLABORATIVE PROJECT FOR THE REMEDIATION OF AGRONOMIC SOILS CONTAMINATED WITH CAESIUM

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Abstract

After a nuclear accident, such as those at the Chernobyl and Fukushima Daiichi nuclear power plants, radiocaesium — due to its volatility — is the main contaminant that spreads over large areas and stays close to the soil surface for decades. At the end of 2013, under a five year grant from the French Government's Investissement d'Avenir, a large programme was initiated, entitled DEMETERRES, which includes four academic Institutes: CEA, CIRAD, INRA and IRSN, and two industrial companies, AREVA and VEOLIA, both leaders in environmental technologies. The main goal of this programme is to develop physico-chemical and biological technologies for the remediation of soils contaminated by caesium. Phytoextraction of radiocaesium is a promising technique for the treatment of large areas of contamination, but the major drawback of this technology is that it takes decades. I It was therefore necessary to search for gene candidates able to increase the rate of phytoextraction of Cs. In the framework of this programme, the plant approaches were coordinated, such as the impact of root architecture on caesium acquisition, the role of potassium transporters, potassium being chemically homologous to Cs, and the impact of the membrane potential and organic acid excretion by plant roots on Cs uptake. Two model species were used: Arabidopsis and Rice, which are genetic models for dicotyledonous and monocotyledonous, respectively. A large collection of mutants in important genes was created for potassium transport, root architecture, organic ion excretion and screening for caesium toxicity. Mutants were affected in caesium transport in hydroponic conditions, some exhibiting an enhanced Cs content in leaves up to several fold, others with a decreased content by up to 50%. These genotypes are now grown by collaborators at the University of Tokyo on soils extracted from a contaminated zone in Fukushima to confirm the potential value of these genes to create plants specifically dedicated to phytoextraction of Cs, or conversely plants with a low level of contamination on contaminated soil.

1. INTRODUCTION

In situ restoration of contaminated soils can be achieved by phytoremediation. A drawback of this technique is the long time needed, and the fact that it can only be performed on soils with low or medium levels of contamination. However, it complements ex situ remediation that remains the only method of treatment for heavy levels of contamination. Caesium is chemically an analogue of potassium. The phytoextraction process is based on the transport of radioelements in plants using plant transporter mechanisms usually dedicated to plant nutrition. The first assays done in Japan have revealed low efficiency and the need for a better understanding to enhance the capability of plants to uptake and translocate Cs. Various strategies, based on genetic approaches, have been developed.

2. FIT THE ROOT ARCHITECTURE TO THE CONTAMINATION PROFILE

Frequently, Cs is strongly linked to small clay particles and stays in the top centimetres of the soil. Adaptation of roots architecture to the contaminated zone, e.g. managing root architecture to locate the roots mainly in the first 10 cm, is a way to increase the yield of phytoextraction of radiocaesium. Conversely, deep rooting is another strategy to diminish the uptake of surface contaminants such as Cs. For that purpose, different genes have been targeted in rice, which regulate the angle of development of secondary roots (see Fig. 1). Work is now under way to characterize the impact of rice root architecture on Cs uptake and translocation using contaminated soils from Fukushima and on an artificial substrate based on perlite which mimics clay and permits construction of a gradient of Cs contamination.

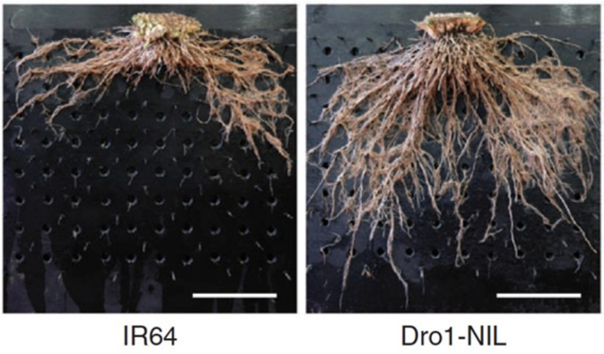

FIG. 1. Rice lines with different root architecture.

3. INCREASING THE RADIOELEMENT PHYTO-AVAILABILITY

Some substrates exuded by roots, such as organic acids (malate, citrate) and protons, are known to increase the phyto-availability of minerals such as Fe or Al by modifying their chemical speciations. We are studying a way to modulate organic acid and proton exudation by means of genetics, targeting genes that control these processes at the level of transporters, proton pumps and organic acid transporters and transcription factors playing on these processes in *Arabidopsis thaliana*.

Validation of this concept is under way using contaminated soils from Fukushima in the framework of collaboration with the University of Tokyo.

4. INCREASING THE UPTAKE AND TRANSLOCATION OF RADIOELEMENTS

Using chemical analogy, and based on competition studies, Cs uptake in plants had been shown to proceed mainly by potassium transporters and to be potentially subject to potassium homeostasis. In *Arabidopsis thaliana,* as much as 90–100 genes are putative potassium transporters, some of them described for potassium uptake and a minority described as being able to transport Cs such as HAK5 (alias KUP13) and KUP9. We established a large collection of homozygous knockout mutants from the HKT, KUP, KEA, CAX and CNGC shaker channels families. Interesting mutants were isolated on the basis of their Cs sensitivity or tolerance concerning growth and chlorophyll synthesis.

Depending on the genes considered, some knock-out lines placed in hydroponic conditions exhibited a change in the transfer of radiocaesium to shoots from 200% to 50% when compared with the wild plant. Studies are under way for the full characterization of the product of gene A. Gene A mutant was able to hyperaccumulate Cs (see Fig. 2). Mutant performances regarding potassium and Cs uptake and translocation on contaminated soils from the Fukushima area are under way. The corresponding genes could be targeted in agronomic crops to increase (phytoextraction) or decrease (safe food) the transfer of caesium.

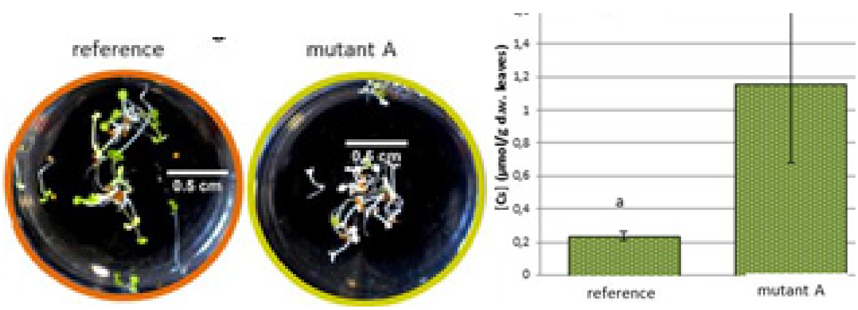

FIG. 2. (a) Cs toxicity in germinated seedlings and seven day Cs; (b) accumulation in 35 day old plants of mutant line A affected (knocked-out) in a potassium transporter compared with reference wild type line Col0. (a). 100µM potassium and 300 µM Cs; (b). µM potassium and 1 µM Cs.

5. THE SAFE FOOD APPROACH

When soils present moderate contamination, another strategy may be used, consisting of growing plants with a limited capability to transfer Cs from the soils to plant tissues. Such an approach depends on genetic determinants. This approach was started using rice and targeting potassium transporters from KUP/HAK/KT and HKT families, the most likely candidates to exhibit a high affinity transport of Cs. As previously mentioned, potassium transporters are numerous in plants and a first assay was a heterologous expression in yeast in order to determine the selectivity of the encoded transporters concerning potassium and Cs, respectively. A mutant yeast line deficient in the main potassium transporters was used, *trk1 trk2 tok1*. Yeast growth was followed in the presence of various potassium and Cs concentrations coupled with the determination of Cs and potassium uptake by yeast transformed lines. This approach showed that several members exhibited a large permeability to Cs. However, when expressed in Xenopus oocytes, only one rice transporter exhibited a high affinity transport of Cs. Work is now underway to characterize the role of this transporter in plants using reverse genetics.

GROWTH AND RADIOCAESIUM ACCUMULATION OF *Brassica rapa* L. Var. PERVIRIDIS GROWN IN THREE DIFFERENT CAESIUM CONTAMINATED FUKUSHIMA SOILS AS INFLUENCED BY POTASSIUM SOLUBILIZING BACTERIA INOCULATION

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Abstract

Potassium supply exerts the greatest influence on plant radiocaesium uptake from soil solution. The presence of potassium solubilizing bacteria (KSB) increases the availability of K+ in the rhizosphere, thus enhancing the cationic interaction between potassium and Cs. In the study, five KSB isolates were obtained from soybean rhizosphere on modified Aleksandrov medium containing mica as potassium source. Based on biochemical and 16S rRNA gene sequence analysis, the bacteria were identified as *Bacillus aryabhattai* MG774424, *Pseudomonas umsongensis* MG774425, *P. frederiksbergensis* MG774426, *Burkholderia sabiae* MG774427, and *P. mandelii* MG774428. The KSB isolates were evaluated for plant growth promotion, potassium uptake and radiocaesium accumulation of komatsuna in three different caesium contaminated Fukushima soils. Inoculation with KSB showed beneficial effects on plant growth and increased the overall plant biomass production (~40%). KSB inoculation also significantly increased the radiocaesium accumulation, with much greater magnitude in roots than in shoots. The results indicate that KSB inoculation may be essential in managing caesium contaminated soils and manipulating radiocaesium transfer from soils to plants.

1. INTRODUCTION

Radiocaesium is one of the most important artificial radionuclides produced by nuclear fission. Its occurrence in the terrestrial environment is by the authorized discharge of nuclear waste, by nuclear weapons testing and by accidental release from nuclear facilities, such as the Chernobyl accident in April 1986 and the more recent

Fukushima Daiichi accident in March 2011. Radiocaesium contaminated soil has a long term radiological impact due to its long physical half-life (^{137}Cs $t_{½}$ of 30 years and ^{134}Cs $t_{½}$ of 2 years) [1, 2], emission of gamma radiation and its biological activity [3]. This causes the greatest concern because of its harmful effect on agriculture and stock farming.

Phyto-transfer or accumulation has been investigated for a number of plant species for soils contaminated with radiocaesium [4–7]. These trials have shown that manipulations of the growth media ionic concentrations and ratios (e.g. K+: Cs+) may affect the radiocaesium phyto-transfer dynamics. Methods have been devised to affect the radionuclide phyto-transfer dynamics, including enhancing the amount of plant biomass in the contaminated soils per unit area or increasing concentrations of metals and radionuclides in plants [8–9]. In most cases, inoculation of plants with plant growth promoting microorganisms can increase plant biomass and uptake of metals and radionuclides [10–12]. Therefore, microbial inoculation in plants has attracted much attention because of the promise for practical application to manage or for possible enhanced phyto-transfer in contaminated soils.

2. METHODS

2.1. Soil sampling and laboratory analyses

Bulk surface soils (0−10 cm depth) were collected from the three agricultural field in Nihonmatsu, Fukushima Prefecture, with elevated concentrations of radiocaesium. Soil physico-chemical analyses were carried out by standard analytical methods and procedures.

2.2. Potassium solubilizing bacteria isolation, pot experiments and gamma spectrometric analysis

The five best performing potassium solubilizing bacteria (KSB) were isolated from the rhizosphere of soybean using a modified Aleksandrov medium. Based on biochemical and 16S rRNA gene sequence analysis, the bacteria were identified as *Bacillus aryabhattai* MG774424 (J7), *Pseudomonas umsongensis* MG774425 (J8), *P. frederiksbergensis* MG774426 (K1), *Burkholderia sabiae* MG774427 (K2), and *P. mandelii* MG774428 (K3). The KSB isolates were evaluated for plant growth promotion, potassium uptake and radiocaesium accumulation of komatsuna in three different caesium contaminated Fukushima soils. The total radioactivity concentrations of radiocaesium (^{134}Cs and ^{137}CS) in roots, leaves and soil samples were measured using a well-type thallium activated NaI crystal detector with energy range of 15–2000 keV coupled to a multichannel analyser with a dead time of 2.5 μs and a computerized data acquisition system 2480 Wizard² Automatic Gamma Counter (Perkin Elmer, Japan).

2.3 Statistical analysis

Statistical analysis was performed in all obtained data using the SPSS software package (SPSS Inc., Chicago, IL, version 20.0). The data were analysed with a two way analysis of variance (ANOVA). To examine the statistically significant differences ($p < 0.05$) between means, the Tukey–Kramer test was performed.

3. RESULTS AND DISCUSSION

The results indicate that plant growth was stimulated more with bacterial inoculation with an average increase in total biomass production of around 40% (see Table 1). This could mean that KSB inoculation may have enhanced the bioavailability of potassium and utilization efficiency, by which it was considered limiting during the initial analysis, hence higher biomass yield. It was demonstrated that KSB inoculation significantly improved availability of potassium mainly because of its effect on mineral weathering [13]. The results also confirm the findings of earlier researchers where they reported that KSB inoculation resulted in growth promotion and higher potassium contents in plant tissues [14–16]. A significant increase was reported in shoot and root dry yield as well as greater uptake of potassium by cotton and rape due to application of potassium bearing minerals inoculated with potassium releasing strain *Bacillus edaphicus* NBT [17]. It leads to the simplification that the KSB plays an important role in plant nutrition through the increase in potassium uptake by the plant.

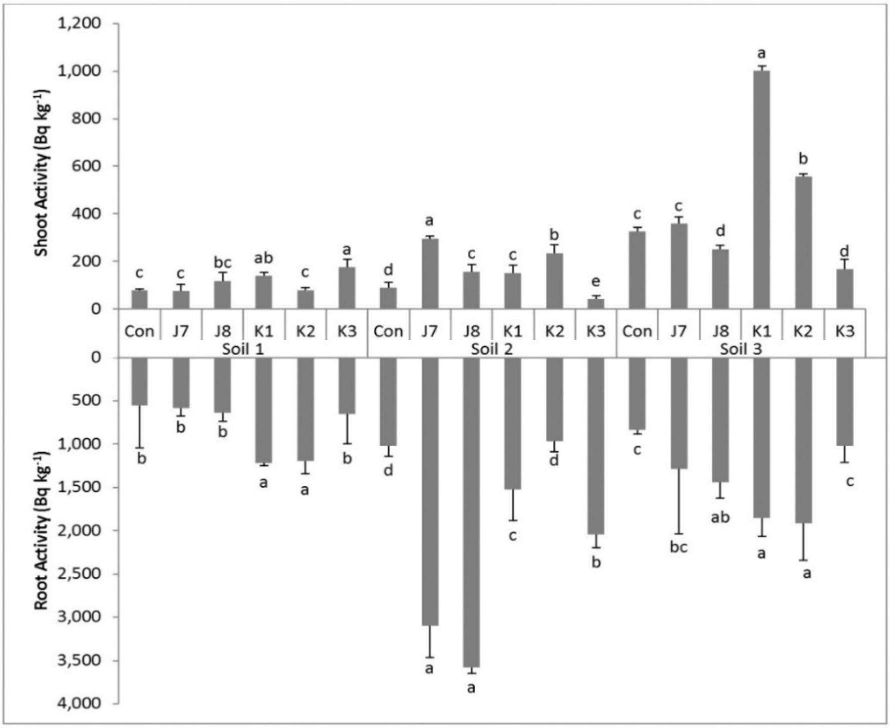
On the other hand, while availability of potassium was considerably increased, as shown by the increase in komatsuna total biomass yield, many of the plants show symptoms of chlorosis and necrosis. These are typical visual symptoms for plants grown in soils contaminated with a high level of Cs [18]; these indications are also considered to be associated with Cs interference with potassium metabolism [19]. Leaves scorching and rolled downwards in komatsuna were observable during growing period. Similar results were also reported on *Amaranthus cruentus* L. grown in soil with spiked Cs level [10]. Plants with significantly higher radiocaesium concentration, such as J7 and J8 inoculated pots in soil 2, showed considerably lower root biomass. The reduced root biomass might indicate caesium radiotoxicity. Avery [20] proposed that Cs intoxication is the result of competition between K^+ and Cs^+ for binding sites on essential K^+ activated proteins.

TABLE 1. EFFECTS OF KSB ISOLATES ON SHOOT AND ROOT YIELD AND BIOMASS INCREASE OF KOMATSUNA 28 DAYS AFTER PLANTING; THE VALUES ARE THE MEAN OF THREE REPLICATIONS (± SD)

Soil	Isolates	Shoot (g)	Root (g)	Total biomass (g)	Increase (%)
Soil 1	Control	$0.67^{b} \pm 0.05$	$0.07^{b} \pm 0.01$	0.74	-
	J7	$0.86^{b} \pm 0.06$	$0.06^{b} \pm 0.01$	0.92	25
	J8	$1.23^{a} \pm 0.07$	$0.18^{a} \pm 0.01$	1.41	90
	K1	$0.84^{b} \pm 0.13$	$0.11a^{b} \pm 0.02$	0.95	29
	K2	$0.78^{b} \pm 0.15$	$0.09a^{b} \pm 0.01$	0.87	18
	K3	$0.80^{b} \pm 0.09$	$0.07^{b} \pm 0.02$	0.87	18
Soil 2	Control	$0.57^{c} \pm 0.15$	$0.06^{b} \pm 0.01$	0.64	-
	J7	$1.28^{a} \pm 0.11$	$0.20^{a} \pm 0.02$	1.48	132
	J8	$1.00^{b} \pm 0.18$	$0.16^{ab} \pm 0.04$	1.15	81
	K1	$0.63^{c} \pm 0.07$	$0.10^{ab} \pm 0.02$	0.73	15
	K2	$1.03^{b} \pm 0.15$	$0.19^{a} \pm 0.04$	1.22	92
	K3	$1.03^{b} \pm 0.13$	$0.14^{ab} \pm 0.03$	1.17	83
Soil 3	Control	$0.93^{ab} \pm 0.06$	$0.19^{a} \pm 0.02$	1.12	
	J7	$0.80^{b} \pm 0.09$	$0.14^{a} \pm 0.03$	0.95	-5
	J8	$0.92^{ab} \pm 0.11$	$0.19^{a} \pm 0.04$	1.11	11
	K1	$1.02^{ab} \pm 0.12$	$0.18^{a} \pm 0.03$	1.20	20
	K2	$1.08^{ab} \pm 0.20$	$0.18^{a} \pm 0.03$	1.25	25
	K3	$1.15^{a} \pm 0.12$	$0.07^{b} \pm 0.01$	1.23	23

Means with common letter(s) within the same column and treatment group are not significantly different from each other (Tukey–Kramer test, P>0.05).

Komatsuna showed a greater ability to accumulate Cs both above and below ground parts as presented in Fig. 1. In general, roots had higher Cs concentrations than shoots for all the bacterial inoculants and across soils. Regardless of soil, significantly higher concentrations of radiocaesium were observed in both roots and shoots in most of the KSB inoculated treatments. Specifically, K3 and K1 showed the highest Cs accumulation in soil 1, while J7 showed highest in soil 2. Moreover, soil 3 inoculated with K1 showed the most radiocaesium accumulation, averaging to around 1000 Bq/kg. The overall higher phyto-transfer of radiocaesium from the soil with bacterial inoculation suggests that KSB application could trigger an increase in radiocaesium uptake while enhancing also the biomass yield of the plant.



Means with common letter(s) within the same column and treatment group are not significantly different from each other (Tukey–Kramer *test*, P>0.05)

FIG. 1. Radiocaesium accumulation in shoot and root of komatsuna inoculated with KSB isolates and grown in radiocaesium contaminated soils.

Total shoot and root radiocaesium in all plants across soils was significantly greater for bacterial inoculation treatment compared to uninoculated control. Caesium concentrations in roots have contrasting values, depending upon the soils used and KSB inoculation treatments. These can be due to some interaction effects between soil and the bacterial inoculants affecting the overall efficiency of solubilization process, hence bioavailability. Roots in soil 2 inoculated with J7 and J8 were among the highest noted in Cs accumulation (>3000 Bq/kg) even higher than the soil activity where they were planted. This suggests the enhanced availability of radiocaesium ions in the soil with KSB inoculation.

4. CONCLUSION

The experiment results demonstrated the advantages of KSB inoculation of the growth and enhanced phyto-transfer of radiocaesium in komatsuna. The results reported here indicate that KSB inoculation may be essential in managing and manipulating radiocaesium transfer from soils to plants. Given that some variability in soil to plant transfer factors has been caused by KSB inoculation, workers interested in managing soil to plant transfer of radiocaesium might consider the benefits of KSB on plant growth promotion and radiocaesium accumulation.

ACKNOWLEDGEMENTS

Appreciation is expressed to the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the Nuclear Safety Regulation Authority (NSRA) of Japan for funding the nuclear research exchange programme. Recognition is also given to Tokyo University of Agriculture and Technology (TUAT) for hosting this project, and to the laboratory of plant nutrition for assistance in setting up the equipment for the laboratory analysis.

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RADIOCAESIUM BIOAVAILABILITY TO FLOODED RICE IN COMPARISON WITH UPLAND RYEGRASS

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Abstract

Attention is focused on mechanisms of the soil–plant transfer of radiocaesium (RCs) to paddy rice in the area affected by the accident at the Fukushima Daiichi nuclear power plant. Paddy rice is cultivated in flooded soils, in contrast to ryegrass grown in upland soil conditions. RCs transfer to paddy rice has importance as a major food crop, while ryegrass is a major forage crop. It is speculated that flooding a soil can enhance the RCs transfer to crop plants due to accumulated ammonium (NH_4) in soils mobilizing RCs by the ion exchange in soils. Pot trials were performed to compare and analyse RCs transfer between paddy rice (flooded) and ryegrass (unsaturated). Paddy soils (n = 9) collected from the Fukushima affected area were either cultivated with rice in flooded conditions or with ryegrass in unsaturated conditions, allowing pairwise comparisons of the RCs transfer. Against this speculation, the soil–plant transfer of RCs was 1.2–14-fold smaller for flooded rice than that for ryegrass ($P < 0.05$). The RCs transfer to rice and ryegrass was negatively correlated to the radiocaesium interception potential (RIP) of soils and to the soil exchangeable potassium (K) content. The RCs mobility in soils, expressed as a soil solution–soil RCs concentration ratio, was on average 1.6-fold smaller for flooded soils than unsaturated soils, despite more NH_4 accumulation in soil solution in flooded soils. The plant RCs concentration was not related to that in the soil solution but sharply increased with the RCs/potassium (K) ratio in the soil solution with a larger slope for rice than ryegrass. A larger fraction of soil pores filled with water in saturated soils increases the diffusivity of K in soil solution and, hence, avoiding K depletion at the root surface of rice and suppressing RCs uptake by cationic competition between K and RCs. It was revealed that the mechanisms ruling RCs bioavailability to flooded rice are similar to what was previously established in unsaturated soils. The findings will contribute to the improved prediction of soil plant RCs transfer for rice grown in the Fukushima affected area.

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1. INTRODUCTION

Attention has been focused on the soil to plant transfer of radiocaesium (RCs) to paddy rice in the area affected by the accident at the Fukushima Daiichi nuclear power plant. Soil chemical analysis revealed that in RCs sorption, potassium (K) plays a double but counteracting role on RCs uptake by plants: Applying K can mobilize RCs in soil solutions by competitive cation exchange reactions on soil particles and can increase the bioavailability of RCs, but K may compete with RCs, block root uptake of RCs from soil solutions and may reduce the RCs bioavailability. The mobilization of RCs is ruled by soil chemistry, while the root uptake of RCs can be explained by plant physiology. Semi-mechanistic models predicting the transfer of RCs were developed for European soils and for temperate region crops [1].

However, it is still unclear if the mechanisms controlling the RCs transfer to paddy rice grown in flooded soils in Japan are similar to those for upland crops in Europe. The major differences can be in: (a) soil mineralogy; and (b) plant types and agricultural practices. Indeed, a contribution of soil clay fractions of Japanese soils to the sorption of RCs is significantly smaller than that of European soils [2]. Secondly, it could be speculated that the larger soil water content in flooded soils than unsaturated soils can enhance ammonium (NH_4) accumulation in soils, resulting in mobilizing RCs in a soil solution and increasing the bioavailability of RCs. In addition, dilution by increasing water content, on the one hand, reduces RCs concentration in soil solutions but, on the other hand, dilutes K in soil solution. Also, the diffusion coefficient of solutes in soil solution increases with increasing soil water content and, therefore, concentration gradients of K and RCs towards the root surface are less pronounced in flooded soils than in unsaturated soils.

The aims of this study were to better understand the RCs transfer to flooded rice and to explore if the transfer can be predicted with soil and plant properties. The aim was achieved by comparing the RCs transfer to plants between rice grown in flooded conditions and ryegrass grown in unsaturated conditions for the same soils, allowing pairwise comparisons of the RCs transfer between these plants.

2. MATERIALS AND METHODS

Topsoil (n = 9) was collected from paddy fields affected by the accident at the Fukushima Daiichi nuclear power plant. The paddy fields are only cultivated in flooded condition. The soils were labelled with ^{134}Cs, and then the soils were used for pot trials with rice and ryegrass in a glasshouse. Rice was grown by keeping 3 cm depth of flooded water, whereas ryegrass was grown in unsaturated soil condition (field capacity). Young shoots of flooded rice were harvested at 32 d after germination, while ryegrass shoots were harvested at 25 d after sowing. The shoots were oven dried, calcined at 450°C and dissolved in HCl. Soil solution was isolated from wet soils by centrifuge (4000 × *g* for 30 min). The collected solution was passed through a 0.45 μm filter. The ^{134}Cs concentration in the plant (dissolved in HCl), in the labelled soils and in the soil solution was determined by an NaI (Tl) detector. The transfer factor (TF) of ^{134}Cs was calculated based on the definition TF = (^{134}Cs concentration in shoots (Bq/kg DW))/(^{134}Cs concentration in soils (Bq/kg DW)). The K concentration in the soil solution was determined by using an atomic absorption spectrometer and the NH_4 concentration by the colorimetric method. The RIP and exchangeable K content of the soils were determined [2].

3. RESULTS AND DISCUSSION

Contrary to what we expected, the TF of ^{134}Cs to shoots was significantly larger for ryegrass than that for flooded rice, by factors of between 1.2−14, according to paired comparisons ($P < 0.05$, $n = 9$, Fig. 1). The sorption of ^{134}Cs on soils was enhanced for the flooded soils (used for the flooded rice growth) than for the unsaturated soils (for the ryegrass growth) by factors of 1.1−2.5 (detail not shown). This difference in this ^{134}Cs sorption can be explained by the concentrations of K and NH_4 that compete with ^{134}Cs in soils. In soil solutions, the K concentration was, on average, 1.9-fold lower in the flooded soils than in the unsaturated soils, suggesting the dilution. In contrast, the NH_4 concentration in the soil solution was up to 2.1-fold higher in the flooded soils than in the unsaturated soils, but this effect varied between different soil types, indicating a combination of the dilution and accumulation of NH_4 in the soil solution. The accumulation of NH_4 in soil solution suggests nitrification that was less pronounced in relatively reduced condition in flooded soils than in unsaturated soils. The ^{134}Cs concentration in the shoots was unrelated to that in soil solutions, but it sharply increased with the ^{134}Cs/K concentration ratio in the soil solution, with the regression line for ryegrass being significantly higher than that for flooded rice (Fig. 2). This result indicates that the root uptake of ^{134}Cs from the soil solution was significantly larger for ryegrass than rice at the same level of K in the soil solution. The regression obtained for flooded rice showed a linear positive correlation (Fig. 2), similar to that for ryegrass, suggesting that the ^{134}Cs uptake by rice was largely stimulated at lower K concentration in soil solution.

The paired comparison of the ^{134}Cs TF observed was confirmed by a regression linking the TF with RIP, soil exchangeable K and plant types (Eq. (1)). The regression revealed that the TF of ^{134}Cs was larger for ryegrass than flooded rice, with plant type being a significant factor ($P < 0.05$). This regression explained 66% of the variation of the TF.

$$\log_{10}(\mathrm{TF}) = 0.380(\pm 0.093) - 0.302(\mp 0.054)\mathrm{RIP} - 1.09(\mp 0.11)\mathrm{Ex\text{-}K} + \begin{cases} 0.14 & \text{if grass} \\ -0.14 & \text{if rice} \end{cases} (\pm 0.055) \quad (1)$$

The transfer of ^{134}Cs to shoots was negatively correlated to the radiocaesium interception potential and to the exchangeable K content in soils both for flooded rice and ryegrass. A larger fraction of soil pores filled with water in the flooded soils than the unsaturated soils increased the diffusivity of K in soil solution. Therefore, reduced K depletion at the root surface of flooded rice suppressed ^{134}Cs uptake by cationic competition between K and ^{134}Cs.

In conclusion, this study indicated that the mechanisms ruling the RCs transfer to flooded rice are not different from that was previously established for crops grown in unsaturated soils. Ryegrass may be more vulnerable for RCs transfer than flooded rice due to larger plant uptake of RCs by ryegrass than by rice. Less RCs sorption to unsaturated soils than flooded soils also contributed to this difference in the RCs transfer.

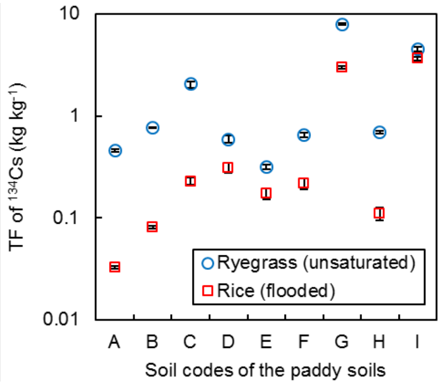

FIG. 1. The transfer factor (TF) of ^{134}Cs obtained from ryegrass (unsaturated) and rice (flooded) grown in the soils (n = 9) collected form paddy rice fields.

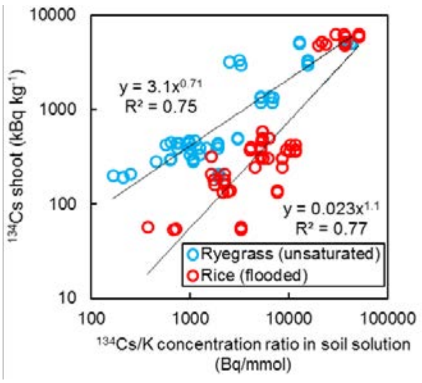

FIG. 2. Correlations between the ^{134}Cs concentration in the shoots and the concentration ratio of ^{134}Cs to K in the soil solution for ryegrass and flooded rice. Linear regression lines are shown for each plant type.

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ANIMALS AND ANIMAL FEEDS

(Technical Session 3)

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RADIOACTIVE CAESIUM CONTAMINATION OF GRASSLANDS IN JAPAN

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Abstract

Grassland renovation, including ploughing and potassium fertilization, is a major countermeasure that has been applied on radioactive contaminated grassland after the TEPCO Fukushima Daiichi nuclear power plant accident in March 2011. Forage growing on renovated grassland last year needed to be surveyed for radiocaesium (^{134}Cs and ^{137}Cs) concentrations to judge if the forage may be released for use or should remain subjected to restrictions. The results of a grassland survey in 2012 showed that 8.1% of renovated grassland produced forage containing radioactive Cs higher than the provisional permissible level of 100 Bq/kg established for cattle and horse forage (assuming water content of 80%). Research has recommended that potassium fertilizer for decontamination should be applied to reach a soil exchangeable K_2O content of 30–40 mg/100 g at a depth of 0–15 cm. Furthermore, the top layer of most contaminated grassland, root mat and litter layer should be mixed well with lower layer soil. It was observed that tillage depth and the extent of soil pulverization was related to a reduction of radioactive Cs concentration of forage. The percentage of forage exceeding 100 Bq/kg of radioactive Cs concentration after the renovation was 0.9% in 2014. Proper potassium fertilization is important in controlling radioactive Cs concentration of forage on renovated grassland. Nitrogen fertilization without potassium on renovated grassland caused an increase of radioactive Cs concentration in forage and resulted in exceedances of 100 Bq/kg in the third year of use. The amount of potassium fertilizer applied for radioactive Cs control is 2−3-fold higher than in ordinary pasture management to maintain soil exchangeable K_2O level. But this high potassium fertilization causes the potassium content of forage to increase by up to 4%, which limits voluntary feeding to cattle because of livestock diseases related to element deficiencies such as grass tetany or milk fever. There are many public pastures on mountains in the Tohoku region. It is hard to apply mechanical treatments to reduce radiocaesium on steep (over 12°) grassland. The renovation method using a radio-controlled crawler tractor was developed for grasslands with steep slopes of 15−30°. Attaching a flail mower, a fertilizer/seed broadcaster, a rotary machine, or a roller to a radio-controlled crawler tractor makes it possible to carry out mowing and collection of clipped vegetation, fertilization and re-seeding, tillage and soil-packing. These actions can be carried out safely on steep grassland because the machines are guided remotely.

1. INTRODUCTION

The Tokyo Electric Power Company (TEPCO) Fukushima Daiichi nuclear power plant accident in March 2011 caused widespread radioactive contamination of grasslands in the Tohoku and Kanto regions (northeast region of Honshu island, Japan) [1–3]. Voluntary restraints on the use of forage carried out in extensive areas where radiocaesium (^{134}Cs and ^{137}Cs) concentration of forage grass exceeded the provisional permissible level of 300 Bq/kg (assuming 20% dry mass). This level for cattle and horse forage was reduced to 100 Bq/kg in February before the establishment of the new limits for foods in April 2012 [4]. Grassland renovation, including ploughing and potassium fertilization, is a major management option used on radioactive Cs contaminated grasslands. About 27 000 ha of contaminated grasslands was renovated for remediation by 2014. Forage growing on renovated grassland needs to be surveyed for radioactive Cs concentration to judge if it may be released for use or restricted from use. A grassland survey in 2012 showed that 8.1% of renovated grassland produced forage containing radioactive Cs higher than the provisional permissible level [5].

2. FACTORS RELATED TO THE CONCENTRATION OF RADIOACTIVE CAESIUM

Extensive research involving renovated grasslands in contaminated areas has shown that potassium fertilizer application during renovation for decontamination should reach a soil exchangeable K_2O content of 30–40 mg/100 g for a tilling depth of 0–15 cm [6]. Furthermore, the highly contaminated top layer of grassland, root mat and litter layer should be mixed well with the lower layer of soil. Several tillage methods in grassland renovation were compared for the effectiveness of reduction (ratio of radioactive Cs concentration in grass against untilled grassland). It was observed that tillage depth and the extent of soil pulverization (percentage by weight of soil particles passing through a sieve of 2 cm mesh) were related to a reduction of radioactive Cs concentration of forage. (Fig. 1). Based on these countermeasures, the level of forage radioactive Cs concentration exceeding 100 Bq/kg after renovation decreased to 0.9% in 2014 [5].

It is recognized that potassium fertilization is important in controlling the radioactive Cs concentration of forage on renovated grassland. While the radioactive Cs concentration of the first harvested forage after renovation decreased to less than 50 Bq/kg in 2012, application of only nitrogen fertilizer on meadow caused a decrease of soil exchangeable K_2O content and a gradual increase in radioactive Cs concentration. This fertilization management technique without potassium resulted in the forage exceeding the 100 Bq/kg limit in 2014. The amount of potassium fertilizer applied to suppress radioactive Cs in forage is 2−3-fold higher than with ordinary management (N:P_2O_5:K_2O 150:150:150 kg/ha) to maintain the soil exchangeable K_2O level. However, this high level of potassium fertilization causes increased potassium content in forage and limits voluntary feeding to cattle because of animal diseases associated with mineral deficiencies such as grass tetany or milk fever. So, we are focusing on proper and precise potassium fertilization for renovated grassland.

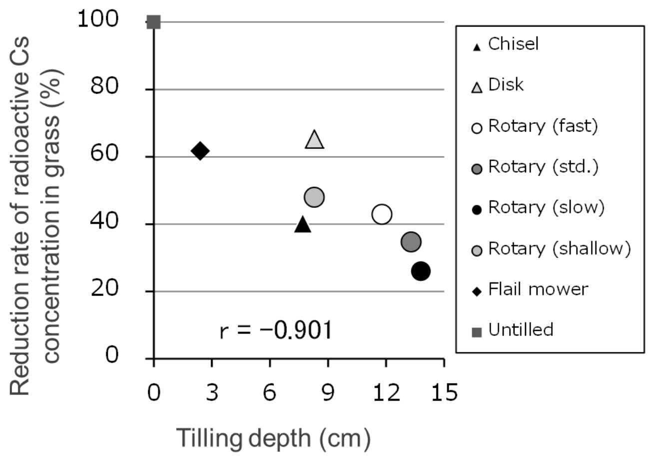

FIG. 1. Effect of tilling depth on the reduction rate of radioactive Cs concentration in grass on renovated grassland compared with untilled grassland.

3. RADIO-CONTROLLED TRACTOR FOR STEEP GLASSLANDS

There are many public pastures on the mountains in Tohoku region. It is difficult to apply mechanical treatments to reduce radiocaesium on steep grassland with a gradient of over 12°. It can also be dangerous for drivers who operate tractors on steep slopes as there is an increased risk of the tractor overturning on a steep incline. A renovation method using a radio-controlled crawler tractor was developed for grasslands with steep slopes up to 30°[7]. Attaching a flail mower, a fertilizer/seed broadcaster, a rotary machine or a roller to a radio-controlled crawler tractor makes it possible to cut contaminated vegetation, fertilize/re-seed, till and pack down soil on steep grasslands (Fig 2).

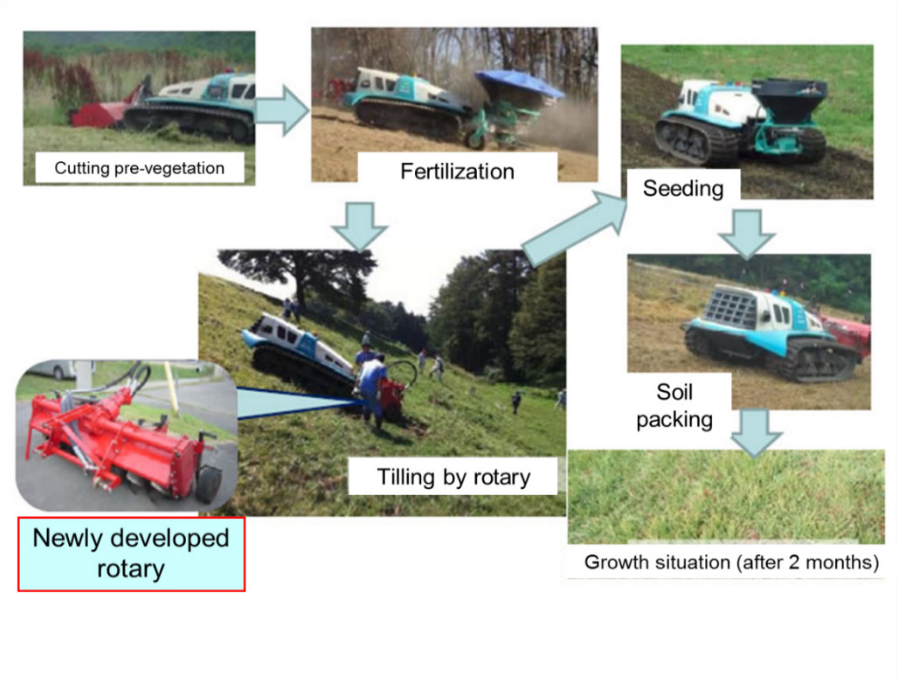

FIG. 2. Operational sequence of renovation on steep grassland using a radio-controlled crawler tractor.

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BASICS OF ANIMAL PRODUCTION UNDER CONDITIONS OF RADIOACTIVE CONTAMINATION

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Abstract

The paper examines the effectiveness of countermeasures implemented in the agricultural sector in Belarus after the Chernobyl nuclear power plant disaster in order to ensure compliance of animal products with the national standards for permissible radionuclide concentrations in foods.

1. INTRODUCTION

The accident at the Chernobyl nuclear power plant occurred on 26 April 1986, on the border between the Ukraine and Belarus. After the decay of short lived radionuclides, the main radioactive contaminants are still caesium isotopes and ^{90}Sr in some areas. Long term compliance with the guidelines and recommendations developed by scientists resulted in a gradual lowering of the national standards for radionuclide concentration levels in major foodstuffs. Although national permissible levels were revised six times, they have always been stricter than the national standards of other affected countries.

2. RESULTS OF THE STUDY

Agricultural practices have shown that with the use of agro-melioration and agro-technical countermeasures it is possible to produce crop and animal products that comply with the permissible levels of ^{137}Cs and ^{90}Sr content in foods and raw materials. Countermeasures can be implemented at different production stages and in different key segments of radionuclide transfer in ‘soil–plant’, ‘feed–animal’, or ‘raw material–end product’ chains. The contribution of cow’s milk, the most critical food product in terms of ^{137}Cs contamination, to internal doses of radiation received by the population can reach 40–80%. In order to reduce internal exposures to the population, it is necessary to apply countermeasures that reduce the transfer of radionuclides into animal fodder. The most effective in terms of dose reduction are countermeasures implemented on pastures and grasslands that are used for meat and milk production (e.g. core improvement of natural grasslands, renovation of cultivated pastures) [1].

Disc harrowing and tillage of grasslands on mineral soils together with the application of mineral fertilizers leads to a factor of 3–5 times reduction of ^{137}Cs and ^{90}Sr uptake by grasses. Core improvement of cultivated meadows also reduces ^{137}Cs transfer grasses, though this approach is less effective in relation to ^{90}Sr. Over the course of time, however, increased concentration levels of radionuclides in forage and hay may occur due to degradation of cultivated grass stands. Therefore, it is important to ensure renovation of forage lands every 3–6 years, depending on the type of grassland and soil characteristics. At the first stage (i.e. during 1986–1990), half-life periods ($T_{1/2}$) of ^{137}Cs transfer to field crops were between several months and 1.5 years ($T_{1/2}$ 1.0-1.8 years for grain crops and 0.8–1.2 years for potatoes).

During the second stage (1991–1998), $T_{1/2}$ was from 5 to 13 years. Application of agricultural countermeasures in the first years after the Chernobyl disaster (1986-1992) had resulted in reductions of 3–8 times of ^{137}Cs transfer to crop yields. Several years after the accident (1992–2010), the contribution of natural processes (caesium fixation by clay minerals and radioactive decay) prevailed over the effect of caesium reducing countermeasures, which dropped down to the average of 50–80%. Nowadays, the major contributor to the reduction of ^{137}Cs concentrations in agricultural produce is radioactive decay. In some cases it is very hard, or even impossible, to implement core improvement of pastures. This is why special drugs are introduced into animal diets to prevent absorption of radiocaesium in the gastrointestinal tract and, therefore, limit its transfer to meat and milk products and subsequently into the food supply and humans.

The most widely known and used drugs are caesium binding sorbents such as Prussian blue, ferrocynes, Giese salt and Nigrovitch salt. The introduction of these drugs has proved to be a reliable countermeasure with sustainable effects, resulting in a 2–5 fold reduction of ^{137}Cs concentrations in milk and muscle tissues of dairy and beef cattle [2–4]. One of the most popular protective measures in Belarus agriculture in the first months after the accident was feeding cattle ‘clean’ forage at the final fattening stage. Due to this countermeasure, production of contaminated meat was rapidly reduced to insignificant figures [5]. Replacing contaminated milk in the human diet with its processed derivates is an effective protective measure that can achieve a reduction of more than ten times of radionuclide intake into the human body. A reduction of 8–10 times of ^{137}Cs and ^{90}Sr concentrations in the end products can be reached by processing whole milk into butter and rennet cheese. Whole milk processing for cream, sour cream and cottage cheese leads to a reduction of 4–6 times. In cases when contaminated land make it impossible to produce crops in compliance with the established standards, or when consumption of animal products contributes to high doses of internal radiation of the population, an effective countermeasure would be to change the production purposes of a farm enterprise. For instance, a collective dose due to strontium and caesium contribution would be 28 times less, when contaminated feeds are used for the purposes of meat production instead of dairy purposes. Thus, by changing the purpose of the usage of grown farm crops it is possible to lower the levels of exposure to the population by 20–30 times [6].

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INFLUENCE OF THE SEASON ON THE LEVELS OF ACTIVITIES IN CROPS FOLLOWING A SHORT TERM DEPOSITION OF RADIONUCLIDES TO AGRICULTURAL LAND

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Abstract

The paper gives an overview of the factors that influence activity levels in foods following radionuclide depositions at different times of the year. It provides examples illustrating the interaction between the season of the deposition and the resulting activity levels in food and doses. The uptake of radionuclides through leaves may be much higher than the uptake through roots, and the uptake through leaves depends strongly on the stage of development of the plants when the deposition occurs. Different crops have different growing periods within the overall vegetation period. Therefore, crops may be affected at very different stages of development. Assessments conducted for radionuclide depositions occurring during the vegetation periods need to address the environmental conditions, as well as practices for farming and animal husbandry.

1. INTRODUCTION

Releases of radionuclides to the environment need to be evaluated according to the principles of radiation protection. Radionuclide transport through the environment and the resulting exposure to the public are the result of a complex interaction of transfer processes and environmental conditions. The potential terrestrial exposure pathways for radionuclides in the environment to humans are summarized in Fig. 1; the pathways include: (i) internal exposure due to inhalation of contaminated air or of resuspended contaminated soil particles; (ii) the transfer of radionuclides in food chains and subsequent internal exposure of humans due to ingestion of contaminated foodstuffs; (iii) external exposure from radionuclides in the air (immersion); and (iv) external exposure from radionuclides deposited on the ground.

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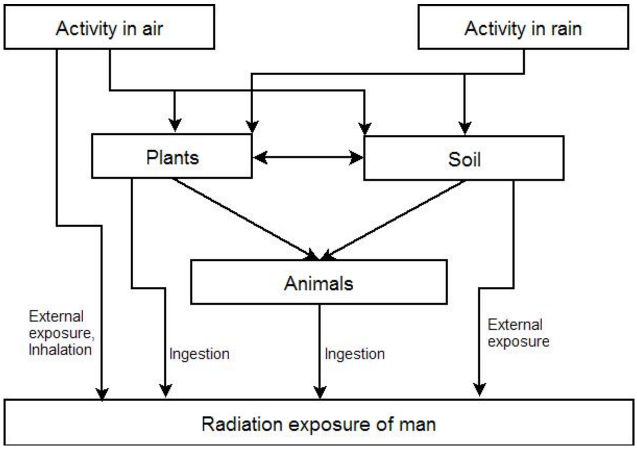

FIG. 1. Simplified scheme of terrestrial exposure pathways subsequent to releases of radionuclides to the atmosphere [1].

For assessing the transfer of radionuclides through food chains, the following processes need to be considered (parameters for their quantification are compiled in Ref. [2]):

— Dry deposition of radionuclides to soil and vegetation.
— Interception of wet deposited radionuclides by vegetation.
— Growth dilution and weathering loss from vegetation.
— Systemic transport of radionuclides in plants subsequent to deposition on the foliage.
— Uptake of radionuclides by plants from the soil and migration and fixation of radionuclides in soil.
— Intake of radionuclides by domestic animals and transfer of radionuclides to animal derived food products such as meat, milk and eggs.
— Modification of activity levels in foods during processing and culinary preparation.

2. INFLUENCE OF SEASONAL FACTORS

The impact of environmental releases of radionuclides on the human food chain depends on the time of year when the release occurs and the agricultural environment becomes contaminated with radionuclides. The term 'seasonality' [3] is used to characterize varying responses to radioactive contamination of environmental samples according to the time of the year when the contamination occurs.

The most obvious effects of seasonality are seen in relation to the morphological development of crops. The increasing leaf area and biomass during the growing period affects: (i) the direct deposition and interception on standing crops; (ii) the loss of radionuclides deposited on the plants through weathering; and (iii) the transport of radionuclides from the foliage to the edible parts. Therefore, a deposition event during winter, when the fields are fallow and domestic animals are indoors, will result in a significantly lower radiological impact than if a similar contamination event were to take place in the summer, before harvest. Once the contaminant has reached the ground, and indirect contamination (root uptake) becomes the dominant pathway, seasonality is usually less significant [3].

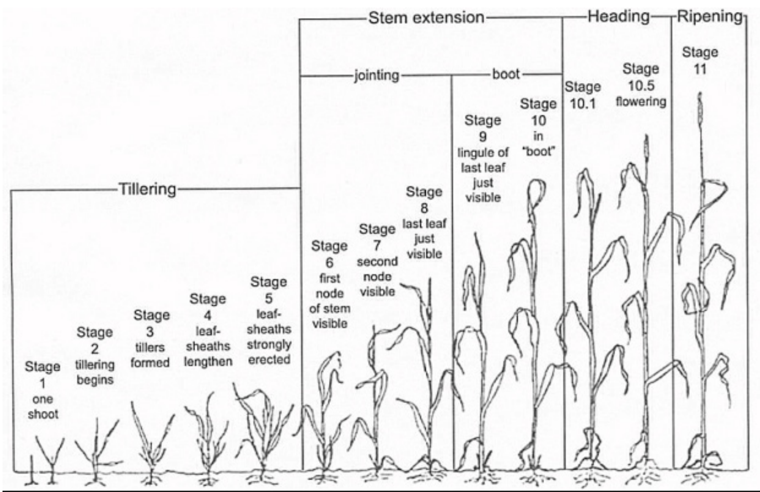

FIG. 2. Stages of development of winter wheat [3].

Therefore, for the radiological evaluation of short term depositions, it is necessary to differentiate whether or not deposition occurs during the vegetation period. Radionuclides, deposited directly on standing crops, may enter the plants and their metabolism may cause much higher activity levels in the part of the plant that is used as food compared with the indirect uptake of radionuclides that first fall on to the land and transfer into crops from the soil through plant roots.

The significance of direct deposition (to plant leaves and stems for example) resulting in enhanced contamination of food crops is illustrated for potatoes and winter wheat in Fig. 3. This illustrates that caesium uptake through the foliage (foliar uptake) may be a factor of 100−1000 higher than through uptake from soil, depending on the stage of plant development when the crops are affected, highlighting a pronounced seasonality effect.

Another phenomenon observed due to seasonality is illustrated in Fig. 4, which shows the time dependence of ^{137}Cs in cow's milk on a farm in Germany following the Chernobyl accident in 1986 [5]. Here seasonality is related to dairy cows grazing either fresh pasture or feeding on dried pasture retrieved from storage (hay). Each dot represents one single measurement; the curves represent the 5-, 50- and 95-percentile of a model simulation. After the deposition, the ^{137}Cs levels in milk declined during the spring and summer of 1986. The animals were fed on fresh grass during the vegetation period and on hay during winter. The decline in spring/summer is equivalent to an effective half-life of about two weeks, due to the loss of ^{137}Cs from the plants' surfaces and the diluting effect due to the growth of pasture grass. However, the ^{137}Cs levels in milk increased again during the winter of 1986–1987 due to the use of contaminated hay that had been harvested in the spring/summer of 1986.

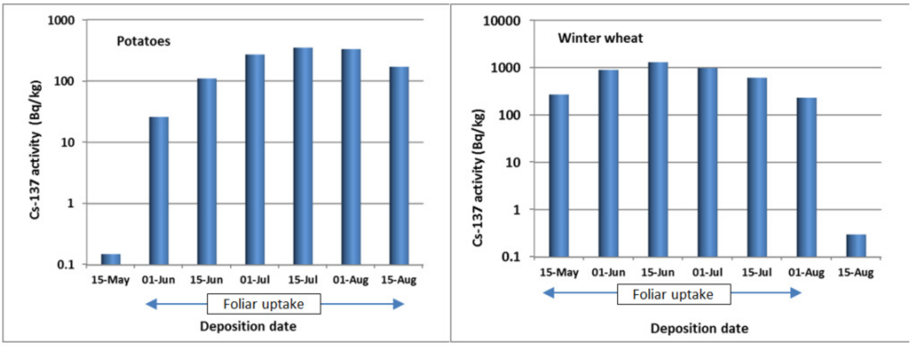

FIG. 3.Measured ^{137}Cs activity concentrations in potatoes and winter wheat subsequent to their exposure to a time integrated air concentration of 1000 Bq h m^{-3} for different deposition dates . [4]. On 15 May, potatoes are contaminated through root uptake only. Harvest of wheat is assumed to occur between 1 and 15 August; the activity level in wheat for 15 August refers to the harvest in the following year, when contamination of wheat is through root uptake only.

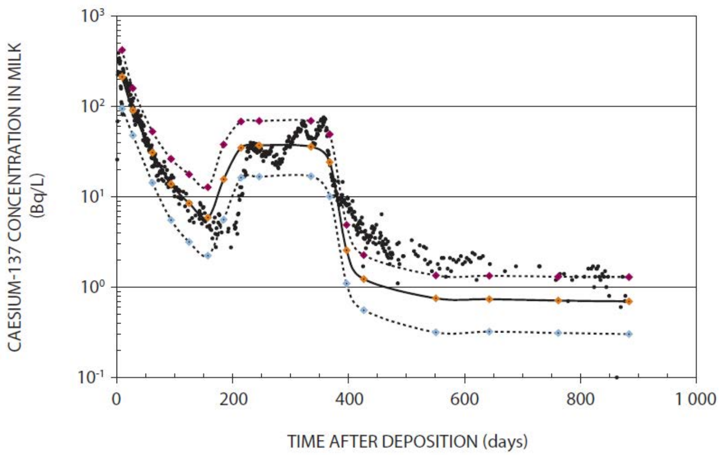

FIG. 4. Measured and modelled activity levels of ^{137}Cs in cow's milk on a farm near Munich, following the Chernobyl accident [5].

3. DISCUSSION AND CONCLUSION

Following short term depositions of radionuclides on agricultural land, the resulting activity levels in crops and foods and the potential exposure to people through ingestion depends largely on the season of the year, when the deposition occurs. The following factors are worth highlighting:

- The uptake of radionuclides through leaves may be very effective and is subject to pronounced seasonal variations in the stage of development of the plants. This contamination process is much more effective than uptake of radionuclides through the roots.
- As the growth of different crops may cover different time slots within the overall vegetation period, the activity levels in different food and feedstuff may vary substantially because the crops may be affected at very different stages of development.
- Therefore, the radiological evaluation of radionuclide depositions occurring during the vegetation periods requires: (i) the careful consideration of the environmental conditions of the affected areas; (ii) the growing periods of crops cultivated in the area; (iii) information on the use of crops as food or feedstuffs; and (iv) the agricultural practices in animal husbandry.

Both the Chernobyl and Fukushima Daiichi nuclear accidents occurred early in the year, during the transition of winter to spring. Therefore, only few crops were affected by direct deposition of radionuclides and the implications for agriculture and trade remained relatively small. Large scale deposition of radionuclides during the peak growing season could have much larger radiological impacts on agriculture. Such implications may need to be explored in order to elaborate solid grounds for contingency planning.

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RADIOACTIVITY MONITORING OF MEAT AND ANIMAL FEEDS AND EMERGENCY PREPAREDNESS IN AUSTRIA

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Abstract

Approximately 2% of the total amount of ^{137}Cs activity released during the Chernobyl accident was deposited within Austria's borders, making it one of the most heavily affected countries in the European Union. Under the Austrian radioactivity monitoring programme, several systems are in place to ensure the consistent monitoring of the environment and to allow for easy detection of any major rise in radioactivity levels across the country. With respect to monitoring of meat and animal feeds, air, precipitation and surface water samples generally contain low levels of artificial radioactivity, while higher levels of ^{137}Cs can still be found in soil samples from certain regions in Austria. Foodstuffs and agricultural products contain very low levels of ^{137}Cs because in agricultural soils caesium is readily bound by clay minerals. However, significantly higher levels of ^{137}Cs can still be found in forest products such as mushrooms and game due to differences between forest and agricultural ecosystems. Mushrooms and game are not consumed in large amounts by the Austrian population and hence the resulting dose is very low. The legal framework in the event of a radiological emergency is set by the Austrian Radiation Protection Act and the intervention ordinance. The countermeasure compendium (Austrian specific catalogue of protective actions) lists appropriate measures to protect the public and contains information for decision makers on choosing suitable measures. This compendium was prepared within the framework of the National Crisis and Disaster Management plan in accordance with the Austrian intervention ordinance and includes results from the EURANOS project. It was primarily developed for large scale radioactive contamination after a nuclear power plant accident. In the case of small scale events, individual measures of the catalog can be considered. However, the countermeasures should be adapted to the specific situation.

1. INTRODUCTION

Apart from a small TRIGA Mark II research reactor, no nuclear reactors are located in Austria. The only facilities handling radioactivity on a regular basis are a radioactive waste management facility in Seibersdorf, as well as medical institutes and research facilities. Artificial radioactivity in the Austrian environment originates mainly from nuclear weapons testing (10%) and the accident at the Chernobyl nuclear power plant (90%).

In April 1986, large amounts of radioactivity were released into the atmosphere after an explosion at the Chernobyl nuclear power plant. Due to the weather patterns at the time the released activity was also deposited in Austria. The extent of the resulting local soil contamination was influenced mainly by the amount of precipitation a region received. About 2% of the total amount of ^{137}Cs activity released during the Chernobyl accident was deposited within Austria's borders, making it one of the most heavily affected countries in Europe [1, 2]. Figure 1 shows the current contamination levels in a newly prepared ^{137}Cs map of Austria for 2016.

2. RADIOACTIVITY MONITORING PROGRAMME

Austria has several systems in place to ensure that the environment is routinely monitored and any major rise in radioactivity levels across the country can be detected easily. The radioactivity monitoring programme comprises an automated radioactivity detection system as well as laboratory based measurements.

The dose rate monitoring probes and automated air monitoring systems have been placed in different locations around the country (Fig. 2) and provide an 'early warning' when heightened levels of radioactivity are detected.

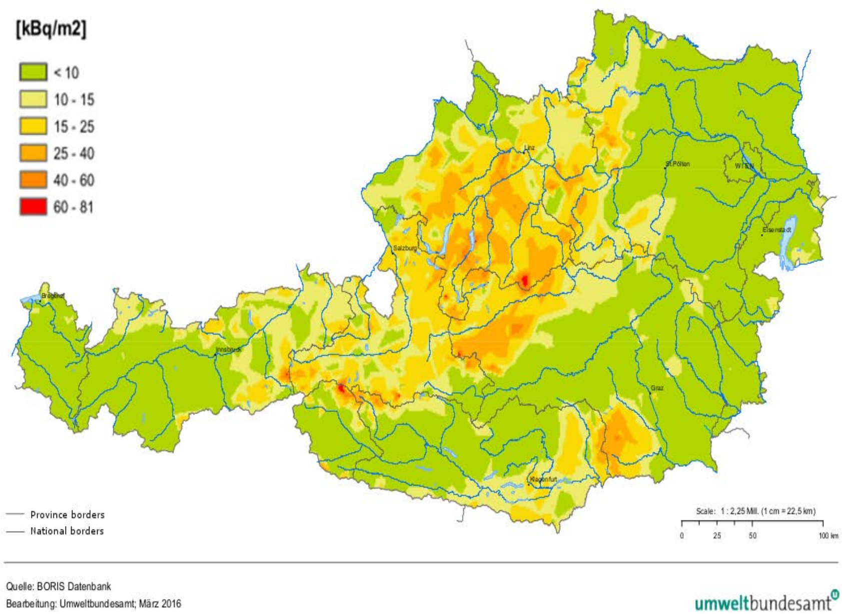

FIG. 1. ^{137}Cs contamination in soil (courtesy of the Environment Agency Austria, 1 May 2016).

The laboratory based measurements are carried out by the Austrian Agency for Health and Food Safety. Our laboratory is equipped with gamma and alpha spectrometry, low level liquid scintillation counters and mass spectrometry.

3. MONITORING RESULTS FOR MEAT AND ANIMAL FEEDS

While air, precipitation and surface water samples generally contain low levels of artificial radioactivity, higher levels of ^{137}Cs originating from the Chernobyl accident can still be found in soil samples from certain regions in Austria.

As caesium is readily bound by clay minerals in agriculturally used soils it is not bio-available for uptake by plants in these areas. As a result, foodstuffs and agricultural products only contain very low levels of ^{137}Cs activity. However, significantly higher levels of ^{137}Cs can still be found in forest products such as mushrooms and game. This phenomenon can be explained by the inability of forest ecosystems to fix caesium in the soil. As a consequence, caesium remains bio-available for uptake by forest vegetation and, through the food chain, by animals that rely on the forest. Mushrooms and game are, however, not consumed in large amounts by the Austrian population and the resulting dose is therefore very low.

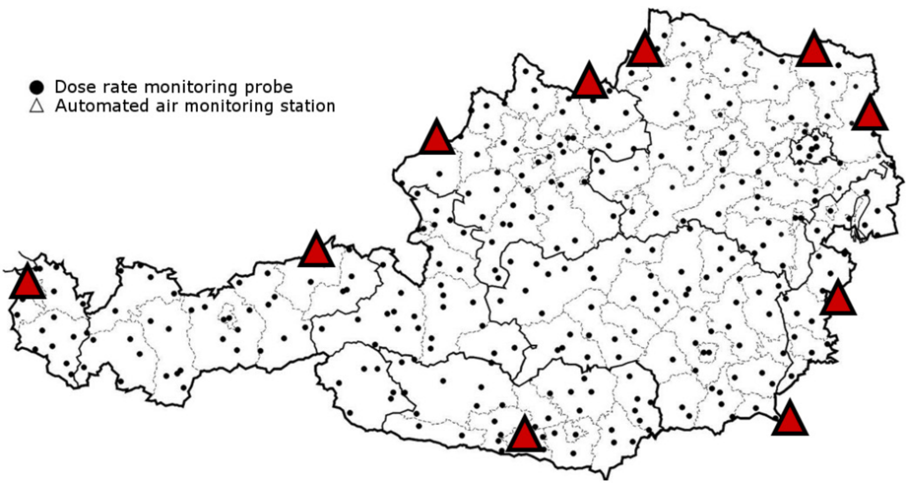

FIG. 2. Locations of the dose rate and automated air monitoring stations in Austria.

4. EMERGENCY PREPAREDNESS

The legal framework in the case of a radiological emergency is set by the Radiation Protection Act and the intervention ordinance. The responsibilities are divided between the provinces and the Federal government.

The countermeasure compendium (Austrian specific catalogue of protective actions) lists measures to protect the public in case of a radiological emergency. This compendium was developed primarily for large scale radioactive contamination after a nuclear power plant accident. In small scale events (e.g. incidents involving radiation sources, radiological terror), individual measures from the catalogue can be considered. However, the countermeasures should be adapted to the specific situation. The countermeasure compendium was prepared within the framework of the National Crisis and Disaster Management in accordance with the Austrian intervention ordinance.

In addition to a general description of the countermeasures, the compendium contains information for decision makers to choose suitable measures (effectiveness, negative effects, etc.). The structure of the action plan takes into account the usual phases of a nuclear power plant accident (early-, contamination, intermediate and late phase).

The Austrian countermeasure compendium includes the results from the European research project EURANOS. In particular, a uniform layout template was used for all countermeasures in reference to EURANOS. In most cases the costs of the countermeasures are difficult to predict. Therefore, a classification of costs was only included in the categories ‘no’, ‘low’, ‘high’ and ‘very high’.

Table 1 details the relevant specific countermeasures for animals and animal feeds together with their respective reference levels. Table 2 shows the maximum permitted levels for radioactive contaminations in foodstuff according to Council Regulation Euratom/2016/52 [3].

TABLE 1. RELEVANT COUNTERMEASURES FOR ANIMALS AND ANIMAL FEEDS

Countermeasure	Reference level
Moving production animals into stables closing stable doors and windows	No reference level, done before plume passage
Prohibition of grazing	Ground contamination ^{137}Cs (e.g. for meat): Cow 1.5E+03 kBq/m², Sheep and goat 2.2E+03 kBq/m²
Restrictions of feedstuff	Pigs 1250 Bq/kg ^{134}Cs and ^{137}Cs Poultry/lambs/calves 2500 Bq/kg ^{134}Cs and ^{137}Cs Other 5000 Bq/kg ^{134}Cs and ^{137}Cs
Usage of non-contaminated feed	Decontamination factor (e.g.) 28 days non-contaminated feed Cow 0.4 Pig 0.5 Chicken 0.65
Changing the time of slaughter	No reference level, done before the meat gets contaminated

TABLE 2. MAXIMUM PERMITTED LEVELS FOR THE RADIOACTIVE CONTAMINATION OF FOOD

Isotope group/food group	Food (Bq/kg)			
	Infant food	Dairy produce	Other food except minor food	Liquid food
Sum of isotopes of strontium, notably ^{90}Sr	75	125	750	125
Sum of isotopes of iodine, notably ^{131}I	150	500	2000	500
Sum of alpha emitting isotopes of plutonium and transplutonium elements, notably ^{239}Pu and ^{241}Am	1	20	80	20
Sum of all other nuclides of half-life greater than 10 days notably ^{134}Cs and ^{137}Cs	400	1000	1250	1000

(Euratom/2016/52)

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FOOD AND COMMODITIES (POST-HARVEST)

(Technical Session 4)

Chairperson

C. M. BLACKBURN
Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture

RADIOACTIVE CAESIUM DYNAMICS DURING FOOD PROCESSING

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Abstract

The accident at the Tokyo Electric Power Company Fukushima Daiichi nuclear power plant, caused by the Great East Japan Earthquake on 11 March 2011, resulted in the release of large amounts of radioactive material (mainly radioactive iodine (^{131}I) and radiocaesium (^{134}Cs and ^{137}Cs)) into the environment that subsequently contaminated agricultural products. The Japanese Government immediately established provisional regulation values (Bq/kg) for the radioactive substances in food and announced that local governments must implement inspections for radioactivity so that foods exceeding the regulation values were not supplied to the market. About one year later, on the 1 April 2012, maximum levels (Bq/kg) for radioactive Cs in foods that were much lower than the provisional regulation limits entered into force. The radiocaesium contamination levels of agricultural products and processed foods have greatly reduced in the past five years since the accident. However, consumers and food manufacturers are still concerned about radioactive materials during food processing and cooking of raw agricultural materials. Elucidation of the behaviour of radioactive Cs during food processing and cooking is necessary for proper risk management by the government and the management of food manufacturing entities, and also for the communication of risk to consumers. Numerous studies on the behaviour of radioactive Cs during the processing and cooking of domestic agricultural foods have been done in Japan. The focus of this paper is on the results obtained from research at the Food Research Institute, on the behavior of radioactive Cs during processing and cooking of brown rice, wheat flour, soybean, and buckwheat grain.

1. INTRODUCTION

The accident at the Tokyo Electric Power Company (TEPCO) Fukushima Daiichi nuclear power plant accident resulted in the release of large amounts of radioactive material (mainly radioactive iodine (^{131}I) and radiocaesium (^{134}Cs and ^{137}Cs)) into the environment that subsequently contaminated agricultural products. The Japanese Government immediately established provisional regulation values (Bq/kg) for radioactive substances in foods after the accident and issued a notification that local governments should implement food inspections based on those values in order to avoid supplying any foods with radioactivity levels exceeding the values for safe consumption. During the five years after the accident, the radioactivity in foods has been decreasing, the types and numbers of foods exceeding the provisional regulation value are extremely small at present [1]. However, consumers and food manufacturers are still concerned about the behaviour of radioactive materials during food processing and the cooking. Different methods of food processing or cooking alter the concentration or the amount of radiocaesium in the final food product. Information about the behaviour of radiocaesium during food processing and cooking helps in risk management for the government and food companies. Furthermore, this information helps in communicating risk to consumers concerned about radioactive substances in food. We provide research results of radiocaesium behaviour during processing and cooking of grains and legumes that have been cultivated in contaminated area of Japan, such as brown rice, wheat, soy bean, and buckwheat.

2. STANDARD LIMITS FOR RADIOACTIVE CAESIUM AND IMPLEMENTATION OF INSPECTIONS IN JAPAN

On 17 March 2011, provisional regulation values (Bq/kg) for radioactive substances in food were established by the government. Approximately one year later, on 1 April 2012, the government enforced a new standard limit (Bq/kg) for radioactive caesium in food. The new standard limit comprised four categories: drinking water; milk; infant foods; and general foods. The activity concentration levels specified as new standard limits are based on an annual dose of 1 mSv through the consumption of food as adopted by the Codex Alimentarius Commission. The inspection of radiocaesium in foods, based on the values of the provisional regulation values and subsequently the new standard limit, has continued since 2011. The government has published summaries of all the inspection results carried out by local governments. Where a food is found to exceed the standard limit, all foods in the same lot must be recalled and disposed of according to government law. Thus, they cannot be shipped domestically nor exported to other countries.

3. BEHAVIOUR OF RADIOACTIVE CAESIUM IN PROCESSING AND COOKING OF AGRICULTURAL PRODUCTS

3.1. Food processing transfer parameters

Significant releases of radionuclides into the environment in past nuclear accidents and atmospheric nuclear weapons testing in the 1960s, has prompted many studies on the behaviour of radionuclides, including radiocaesum, during food processing. The results of such studies show that food processing usually results in a significant reduction in the amount of radionuclides contaminating foodstuffs [2]. In the technical literature [2], the food processing retention factor (F_r) and processing factor (P_f) are applied as the parameters for expressing the behaviour of radionuclides in food processing. The parameter F_r is the fraction of activity of radionuclides that is retained in the food after processing or cooking: F_r is defined as the total amount of radionuclide in processed food divided by the total amount of the radionuclide in the original raw food (Bq processed ÷ Bq raw, F_r cannot exceed 1). Whereas P_f is the ratio of the radionuclide activity concentrations in the food after and before processing (Bq/kg processed ÷ Bq/kg raw for fresh weight). In this report, radiocaesium (Bq/kg) relates to the sum of ^{134}Cs (Bq/kg) and ^{137}Cs (Bq/kg)), F_r and P_f are applied as parameter to present the experimental results.

3.2. Samples

Grain samples of wheat, brown rice, soybean, and buckwheat harvested in Japan in 2011 were used. They were contaminated with radiocaesium from the nuclear power plant accident at various concentrations. The samples were stored at 15°C until required for use.

3.3. Wheat processing and cooking of Japanese udon noodles

Research has investigated the effects of wheat processing and the cooking of Japanese udon noodles [3, 4] (Fig. 1). Japanese winter wheat grains (*Triticum aestivum*) were milled to obtain flour and bran fractions. The F_r values for the flour and the bran were 0.2 and 0.8, respectively. The P_f values for the flour and the bran were 0.4 and 2.1, respectively. These results are in agreement with previous studies [2] And indicate that flour can be made safer for human consumption by milling. Flour is for human consumption, and bran is used mainly as livestock feed in Japan. Wheat grains are generally subjected to monitoring for radiocaesium. For bran however, the change in radiocaesium levels is unsatisfactory because radioactive Cs is concentrated more than twofold in the final product by the milling process. On 15 September 2011, the Ministry of Agriculture, Forestry and Fisheries (MAFF) issued a notification that a milling P_f value of 3 should be applied when considering if radiocaesium levels in wheat are appropriate for the production and marketing of bran with an acceptable level of radiocaesium.

Udon is a popular and typical Japanese cuisine, and udon noodles are usually made by kneading wheat flour, salt, and water. The preparation of udon noodles did not contribute to the removal of radioactive Cs (F_r = 1.0). However, the concentration of radioactive Cs in raw udon noodles decreased (P_f = 0.7) by the addition of salt and water. The boiling process resulted in about 80% removal of radioactive Cs from the udon noodles (F_r = 0.2). The concentration of radioactive Cs in boiled noodles was less than one-tenth of those in raw noodles (P_f = 0.06–0.08). Therefore, milling, udon noodle preparation and cooking considerably reduce radiocaesium levels in the final boiled noodles as ready to eat and in comparison to the radiocaesium levels in the raw wheat grains from which they were derived (Fig. 1).

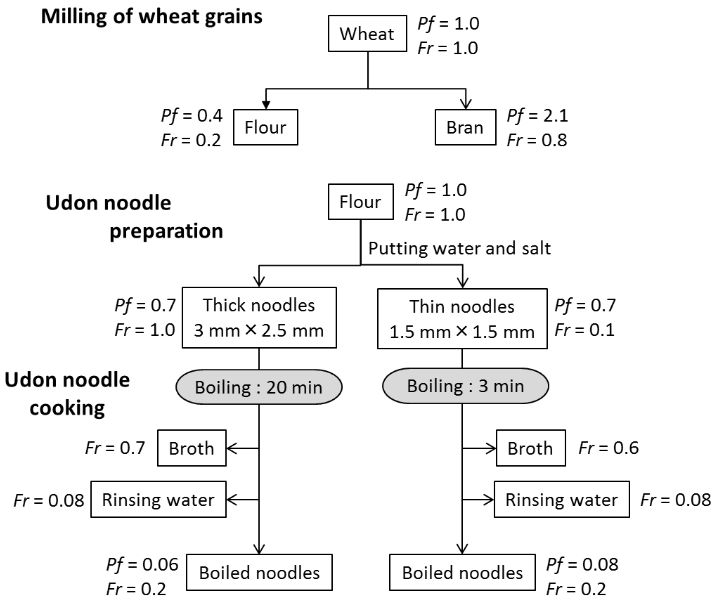

FIG. 1. Behaviour of radioactive caesium in the milling of wheat grains and in the cooking of udon noodles. The processing factor (P_f) is the ratio of the radioactive caesium concentrations (Bq/kg fresh mass) in the food before and after processing or cooking. The food processing retention factor (F_r) is defined as the total amount of the radioactive caesium in processed food divided by the total amount of the radioactive caesium in the original raw food. Values of P_f and F_r are shown as the arithmetic mean value of individual results (n = 3).

3.4. Brown rice processing

Rice (*Oryza sativa*) is a staple food in Japan. Rice polishing removes bran and germ (rice bran) to obtain endosperm (polished rice) as the edible portion for human consumption. Rice bran, like wheat bran, is used as a livestock feed and as a fertilizer. The distribution of radioactive Cs in polished rice and rice bran were approximately 40% and 60%, respectively. The F_r values for polished rice decreased depending on the degree of polishing. When the rice bran is removed completely from the endosperm, the P_f values for polished rice and rice bran were 0.5 and 6.5−7.8, respectively [5]. These results are in agreement with previous studies [2]. The concentration of radiocaesium in polished rice is half of that of brown rice, so the production of polished rice could be safer for human consumption. The situation for rice bran and levels of radiocaesium in animal feed is similar to that of wheat bran. The MAFF also issued a notification that the P_f value of 8 should be applied when considering if it is appropriate to produce and market bran from brown rice.

3.5. Soybean processing

Soybeans (*Glycine max*) is the third major crop in Japan next to rice and wheat. This commodity is consumed after being processed in various ways: extraction, fermentation, boiling, and milling. A soybean grain consists of seed coat, hypocotyl, and cotyledon. The distribution of radiocaesium between the seed coat, the hypocotyl, and the cotyledon were found to be 2.8%, 2.5% and 95%, respectively [6]. No significant difference was seen in the concentrations of radioactive Cs in the soaked soybeans, the hypocotyl and the cotyledon. The concentration in the seed coat was about one-third of that in the hypocotyl and the cotyledon. Most of domestic soybeans are processed into tofu (soybean curd), natto (fermented soybeans), or nimame (boiled soybeans seasoned with soy sauce and sugar) [6]. Dried soybeans are soaked in water overnight as pre-treatment before processing into these products. The soaking process did not have any effect on the removal of radioactive Cs from soybean grains because the removal ratio of radioactive Cs from soybean grain to the soaking water was less than 0.1%. However, the P_f values for tofu, natto, and nimame were 0.1, 0.4 and 0.2, respectively. The F_r values for tofu, natto, and nimame were 0.64, 0.85, 0.45, respectively [6]. The addition of water and removal of okara (tofu refuse) during processing influenced the decrease of P_f and F_r values for these processed foods. Therefore, these soybean processing foods could be considered safer for human consumption in terms of radiocaesium levels in comparison to soybean grains from which they were derived.

3.6. Buckwheat processing and cooking of buckwheat noodles

Buckwheat (*Fagopyrum esculentum*) is one of Japan’s most common crops. Buckwheat seeds are milled into husk, bran and buckwheat flour. The buckwheat flour is the edible portion. The distribution of radioactive Cs between the husk, bran and buckwheat flour components were found to be 30%, 30−40% and 30−50%, respectively. The P_f values for the husk, the bran and the buckwheat flour were 1.3−1.6, 1.4−2.1, 0.6−0.8, respectively. The concentration of radiocaesium in buckwheat flour is less than that of buckwheat seeds from which it was derived. Therefore, buckwheat flour may be considered safer for human consumption in comparison to radiocaesium levels in buckwheat grains from which it was produced. Buckwheat noodles made from buckwheat flour–water dough is a popular and traditional food in Japan. Radioactive Cs was not removed by the raw buckwheat noodle preparation, but the concentration of radioactive Cs in the raw noodles decreased by the addition of water. Cooking removed radioactive Cs from boiled noodles (F_r = 0.5−0.7) by transfer from the noodles into the broth and rinsing water. As a result, the concentration of radioactive Cs in the boiled noodles was less than half of that in raw noodles (P_f = 0.4−0.5).

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FOOD MANAGEMENT FOLLOWING THE CHERNOBYL ACCIDENT

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Abstract

Radioactive fallout in Europe following the Chernobyl accident in 1986 resulted in the contamination of vegetable and animal foods with radionuclides, predominantly ^{131}I, ^{137}Cs and ^{134}Cs. Internal exposure from the ingestion of contaminated food substantially contributed to the radiation dose to the general public. The possibility of people consuming food with unacceptable levels of contamination needed to be addressed by the application of protective and/or remedial actions based on food safety standards established when needed. The type of protective or remedial measures depended on deposition levels, ecological conditions and agricultural practices. Food safety standards were developed since 1986 in the former USSR, European Union (EU) and other countries. In order to prevent food with contamination levels above those specified in safety standards from being consumed, numerous monitoring programmes were implemented and many measurements of radionuclides in food were taken; some of the monitoring programmes are still in force. Various countermeasures were implemented at different stages of agricultural production in the former USSR. In the EU countries, a range of countermeasures have been used to control radionuclide concentrations in animal and vegetable food products. Countermeasures to control foods contaminated with radioiodine proved to be insufficient which led to elevated thyroid doses to children living in the affected areas of the former USSR and resulted in the increased incidence of thyroid cancer after 1990.

1. INTRODUCTION

The accident on 26 April 1986 at the Chernobyl nuclear power plant located 130 km to the north east of Kiev, the capital of Ukraine, was the most severe in the history of the world’s nuclear industry. Wind currents under changing weather conditions spread the radioactive substances over Europe, principally Belarus, the Russian Federation and Ukraine. At the time of the accident, vegetation was well developed both in Central and Southern Europe, which led to its substantial contamination with radioactive material in some areas [1, 2].

2. LEVELS AND DYNAMICS OF RADIOACTIVE CONTAMINATION OF VARIOUS FOODS

In the early phase, the direct surface deposition of many radionuclides dominated the contamination of agricultural plants and of animals consuming them. The release and deposition of ^{131}I caused the most immediate concern. The radioiodine was transferred to milk at a high rate, leading to significant thyroid doses to those consuming milk, especially children. Different crop types, in particular, green leafy vegetables, were also contaminated with radionuclides to varying degrees, depending on the deposition levels, weather conditions during fallout and the stage of the growing season. The direct deposition on to plant surfaces was of concern for about two months [1].

After the early phase of direct contamination of vegetation, uptake of radionuclides through plant roots from soil became increasingly important and showed strong time dependence. Radioisotopes of caesium (^{137}Cs and ^{134}Cs) led to the greatest problems in some affected areas. In addition, strontium (^{90}Sr) caused problems near the reactor. Other radionuclides, such as plutonium and americium (^{241}Am), were either present at very low soil deposition levels, or were not available for root uptake, such as not to cause safety problems in agriculture [1].

In general, there was an initial substantial reduction in the transfer of radionuclides to agricultural vegetation and animals, as would be expected, due to weathering, physical decay, migration of radionuclides down the soil column and reduction in radionuclide bioavailability in soil, especially in the first few years. However, in the next decades there was little further decline and increased long term half-lives have been difficult to quantify with precision.

‘Wild foods’ obtained from the forest, such as mushrooms, berries, game animals and lake fish, have become contaminated with radiocaesium following the Chernobyl deposition. The highest levels of contamination have been observed in mushrooms, which is due to their great capacity to accumulate some mineral nutrients as well as radiocaesium. Reduction in radioactive contamination of mushrooms with time was extremely slow, with half-lives of one to two decades. This is also relevant to the meat of game animals such as deer and moose, which are hunted and eaten in some European countries, especially in Arctic areas. Significant seasonal variations occur in the radiocaesium whole body content in these animals due to the seasonal availability of foods such as mushrooms and lichens.

The radiocaesium activity concentrations in foodstuffs were influenced, not only by deposition levels, but also by soil types, management practices and types of ecosystem. The major and persistent problems in the affected areas occur in extensive agricultural systems in soils with high organic or sand contents and where animals graze in unimproved semi-natural pastures which are not ploughed or fertilized.

In the long term, ^{137}Cs in meat and milk remain the most important contributors to human internal dose. As its activity concentration has been decreasing very slowly, 3% to 7% per year, the contribution of ^{137}Cs to dose may continue to be significant in some areas for decades to come [1, 2].

3. ASSESSMENT OF DOSES FROM INGESTION

Assessment of radionuclide intake with food and drinking water was primarily based on the numerous measurements of ^{131}I, $^{134,137}Cs$ and ^{90}Sr, which have been performed all over Europe and especially in the three most affected countries. ^{137}Cs was mostly determined in raw animal products (milk, meat, etc.); the number of these measurements performed since 1986 and available for dose estimations comprises a few million [1].

The thyroid dose from ^{131}I was mainly due to the consumption of fresh cow's milk and, to a lesser extent, of green vegetables; children on average received a dose that was much greater than that received by adults because of their small thyroid mass and a consumption rate of fresh cow's milk that was similar or larger than that of adults [1, 2].

Assessment of internal doses of the public caused by the intake of food contaminated with ^{137}Cs, ^{134}Cs and, to less extent, of ^{90}Sr, was a part of the radiation monitoring programme aimed mainly at substantiating the effectiveness of countermeasures and remediation programmes, but also to forecast adverse health effects and provide justification for corresponding health care measures.

The deviation in dose to critical groups compared with settlement average values varied by a factor of about 3 for internal exposure. The group mostly subjected to internal exposure from ^{134}Cs and ^{137}Cs were adults consuming both locally farmed animal commodities (e.g. milk, dairy products, etc.) and natural food collected from the wild (e.g. mushrooms, lake fish, berries, etc.) in amounts exceeding average consumption rates.

4. PROVISIONAL STANDARDS FOR RADIONUCLIDES IN FOODS

The concept of temporary permissible levels (TPLs) of human-made radionuclides in food products becomes essential following large radionuclide releases to the environment caused by severe nuclear or radiological accidents. Post Chernobyl accident, TPLs were developed for the first time in many countries and widely used [1, 3].

There are two historically established systems for the regulation of radionuclides in foods. One of them is based on long term observation (i.e. a few decades) of TPLs established for foods and fodders; that approach ensures the safety of the TPLs used since 1986. The European Commission follows this approach, which is useful in more distant regions where the public dose is low from the outset.

With regard to other methodologies, TPLs originally established in 1986 were later periodically reduced after accounting for the natural reduction of the radionuclide content in foods and the effect of countermeasure (see Fig. 1). That approach was used by the former USSR Soviet National Committee on Radiation Protection (NCRP) to advise agricultural producers with the aim of stimulating technological improvements and the application of countermeasures. After 20 years it turned out this methodology was in line with the current ICRP advice on the application of reference levels. This approach is useful in regions where dose to the public is comparable to the reference dose level, or exceeds it, and where therefore active remediation measures are applied.

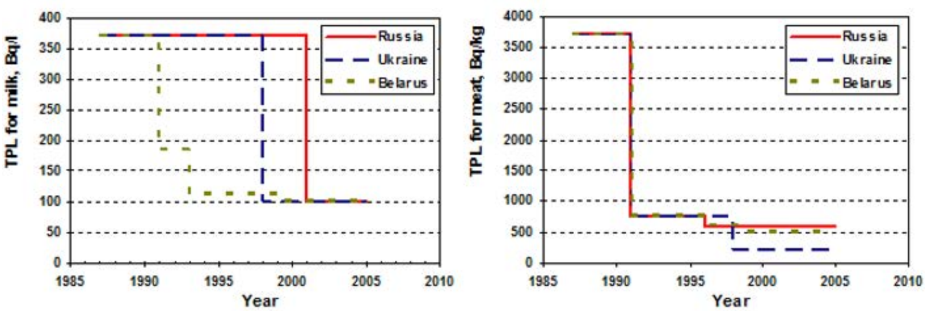

FIG. 1. Changes with time of TPLs for milk and meat introduced in 1986 in the former USSR and later in Belarus, Russian Federation and Ukraine [1].

5. MONITORING AND INSPECTION OF RADIONUCLIDES IN FOODS

An important component of the radiological regulation of foods is the system of radiation measurements. Here one should distinguish between systematic monitoring aimed at current internal dose assessment and large scale radiation measurements aimed at the inspection of food consignments and compliance with TPLs. Those two kinds of radiation measurements have different goals and are usually conducted by different methodologies (food sampling, treatment and measurement, data registration and interpretation). Therefore, mutual use of data obtained within two different methods is limited.

6. COUNTERMEASURES (PROVISION OF CLEAN FOODS AND SYSTEM OF AGRICULTURAL MEASURES)

In areas contaminated with radionuclides above 0.6 MBq/m^2 of ^{137}Cs, the implementation of agricultural countermeasures and restrictions to limit the consumption of local natural food (that can be collected form the wild) has been mandatory and this has substantially reduced internal dose to the public [1, 4].

Countermeasures applied in the early phase of the Chernobyl accident were only partially effective in reducing radioiodine intake via milk consumption, because of the lack of timely information about the accident and guidance on recommended actions, particularly for private farmers [1].

The more effective countermeasures employed in the early phase were the exclusion of contaminated pasture grasses from animal diets and the rejection of milk with high radioiodine content. The slaughter of cattle was often carried out, but it was unjustified from a radiological point of view [1, 4].

Several months after the accident, long term agricultural countermeasures against radiocaesium and radiostrontium were effectively implemented in all contaminated regions; they included cultivation of hayfields and pastures, feeding animals with clean fodder and obligatory milk processing. The most important precondition was the radiation monitoring of agricultural lands, feeds and foodstuffs, including in vivo monitoring of cattle.

The greatest long term problem in the former USSR has been radiocaesium contamination of milk and meat. The cultivation of hayfields and pastures, and clean feeding of cattle are the most important and effective agricultural countermeasures in this regard. In the long term, the efficiency of environmental countermeasures remains at a constant level.

In Western Europe, a number of countermeasures have been used to limit the impact on animal products, especially those from uplands and forests where radiocaesium remains bioavailable and due to the subsequent high and prolonged uptake of radiocaesium in the affected extensive systems [1, 4].

7. WHY INTERVENTION IS IMPORTANT (HEALTH EFFECTS FROM INTERNAL EXPOSURE)

Since early 1990s, the incidence of thyroid cancer among children and adolescents, who were living in the affected areas in spring 1986 started to increase. More than 20 years after the Chernobyl accident, the number of cases of thyroid cancer in those who had been children or adolescents at the time of the accident exceeded 7000, and a substantial fraction of them has been caused by radioiodine intake [2].

As regards long term whole body exposure from ^{137}Cs and ^{134}Cs, the potential increase of cancer by 3–4% of the spontaneous incidence rate in the more affected areas of Belarus, Russian Federation and Ukraine was predicted for total (external and internal) exposures, about half of it due to internal exposure. Such a small increment will hardly be detected in any epidemiological studies; so far there has been no firm indication of that Chernobyl related health effect [2].

8. LESSONS

Internal exposure from ingestion contributed substantially to the radiation dose of the general public caused by the Chernobyl accident, i.e. it dominated in the thyroid dose and comprised more than 40% of the collective effective dose in the affected areas of Belarus, Russian Federation and Ukraine (not including internal thyroid dose).

Internal dose to the general public caused by the intake of food with ^{137}Cs and ^{134}Cs depends strongly on soil conditions and agricultural practices. The contribution of transuranic elements to the internal dose was negligible. Effective internal doses to children (not including internal thyroid dose) were generally no higher than doses to adults.

The collective internal effective dose of residents of the affected areas of Belarus, Russian Federation and Ukraine of more than 40% of the total collective dose would be substantially larger if countermeasures were not applied.

Food safety standards were developed since 1986 in the former USSR, EU and some other countries. Numerous radiation measurements of food samples aimed at prevention of consumption of foods contaminated above safety standards have been conducted worldwide; some of the monitoring and inspection programmes are still in force.

Various countermeasures were implemented at different stages of agricultural production in the former USSR, and later in Belarus, Russian Federation and Ukraine. In some EU countries, a number of countermeasures has been used in animal husbandry in upland, forested and Arctic areas.

Countermeasures against the ingestion of foods contaminated with radioiodine proved to be insufficient, which led to elevated thyroid doses to children living in the affected areas of the former USSR and resulted in increased incidence of thyroid cancer in Belarus, Russian Federation and Ukraine after 1990.

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COUNTERMEASURES ON AGRICULTURAL AREAS AFTER THE CHERNOBYL AND FUKUSHIMA ACCIDENTS[1]

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Abstract

Following the accident at the Chernobyl nuclear power plant on 26 April 1986, considerable quantities of radioactive material were released into the atmosphere, contaminating the food and feed of several European countries at significant levels. Measures were taken to ensure that agricultural products were only introduced into the European Union market according to common arrangements to safeguard the health of the population while maintaining market integrity. This accident significantly impacted the agricultural sector. About 23% of Belarus territory (46000 km²), with 2.2 million people and 1.8 million ha of agricultural land, was contaminated with ^{137}Cs (37 kBq/m²), of which 265 000 ha were totally excluded from the agricultural system. A large number of countermeasures were implemented in response to the magnitude of radioactive contamination in the environment. Radionuclide levels in major food products significantly decreased, particularly in the agricultural production of the major contaminated territories, when compared with levels in the first years after the accident. In 2011, Japan also faced large scale contamination of its land, and subsequent countermeasures had to be placed on agricultural production. The experience gained during the response to the Chernobyl accident was used initially, and then countermeasures were adapted to the specific nature of agriculture and soil in the affected region of Japan. One of the crucial problems related to agricultural production in contaminated districts is to prevent or reduce the transfer of radionuclides from the environment into food products. This issue can be addressed by a set of actions to reduce the migration of radionuclides from 'soil–plant' and 'plant (e.g. forage)–animal product (e.g. meat and milk)'.

1. INTRODUCTION

Following the accident at the Chernobyl nuclear power plant on 26 April 1986, considerable quantities of radioactive material were released into the atmosphere. As a result, this accident significantly impacted the agricultural sector. Environmental countermeasures have been implemented since 1986 to urban, forest, aquatic and agricultural ecosystems [1]. For instance, about 23% of Belarus territory (46000 km²), populated by 2.2 million people and comprising 1.8 million ha of agricultural land, were contaminated with ^{137}Cs (37 kBq/m^2). Some 265 000 ha of agricultural land were totally excluded from the agricultural system [2, 3]. Food and livestock feed in several European countries were also contaminated to significant levels. As regards the European single market, measures have been taken to ensure that agricultural products could only be introduced into the European Union market according to arrangements common across the European Union (EU) and European Economic Area (EEA) countries. The objective was to safeguard the health of the EU and EEA population while maintaining the integrity of the single market.

2. COUNTERMEASURES IMPLEMENTED IN AGRICULTURAL AREAS AFTER THE CHERNOBYL ACCIDENT

A large programme of countermeasures was implemented to protect human health from radioactive contamination. The implementation of agricultural countermeasures after the Chernobyl accident has been extensive, both in the most severely affected countries of the former USSR and in western Europe. In the first weeks after the accident, the main aim of countermeasures in the USSR was to lower ^{131}I activity concentrations in milk and to prevent contaminated milk from entering the food chain. The measures included preventing farm animals from feeding on contaminated pastures (changing from pasture to indoor feeding of uncontaminated feed) and the processing of rejected milk (mainly converting milk to storage products such as condensed or dried milk, cheese or butter) [1]. From June 1986, other countermeasures aimed at reducing ^{137}Cs uptake into farm products were implemented. Particularly in the field of agricultural production for the contaminated territories, the radionuclide concentration in the main food products significantly decreased compared with the first years after the Chernobyl disaster. Impressive results were achieved between 1987 and 1990 through the on-farm implementation of complex agro-technical, agrochemical measures, zootechnical and veterinary measures designed to reduce the transfer of radionuclides (^{137}Cs and ^{90}Sr) from soils to plants or fungi and through to animals.

The key focus of the remediation strategy for intensive agriculture production was the implementation of countermeasures aimed at lowering ^{137}Cs activity concentrations in milk and meat. For example, in 1986−1987, the commercial production of milk with a higher than permissible content of ^{137}Cs amounted to 524 600 tons. However in 2008, in the most severely contaminated area of Gomel Oblast only about 90 tons of milk with ^{137}Cs levels from 100 to 370 Bq/L was produced and supplied for further processing. The levels of ^{137}Cs in the milk produced by the farms of Mogilev Oblast and in Brest Oblast did not exceed 37 Bq/L and 65 Bq/L respectively (with the permissible level of 100 Bq/L). The main aim of agricultural countermeasures was to achieve radionuclide activity concentrations in food products below action levels and to minimize the total quantity of radionuclide activity in agricultural production for consumption and/or distribution. From 1992 to the present (i.e. 30 years after the accident), the use of agrochemicals and agro-technical measures has continued despite financial constraints. For instance, in Belarus, recommendations were developed for the management of agricultural production in terms of the radioactive contamination of land, as well as the permissible levels for caesium and strontium in food products and drinking water. The system of protective measures applied for agricultural production is shown in Fig.1 and will be detailed during the presentation (soil treatment, caesium binders, etc.).

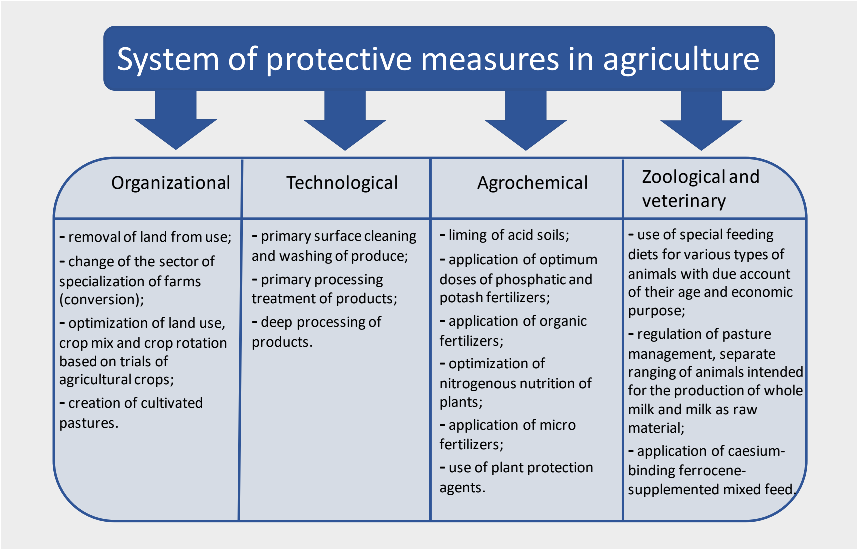

FIG. 1. System of protective measures used in agriculture in Belarus [4].

3. COUNTERMEASURES IMPLEMENTED IN AGRICULTURAL AREAS AFTER THE FUKUSHIMA DAIICHI ACCIDENT

After the Fukushima Daiichi accident, large areas of land in Japan were contaminated with radiocaesium. Countermeasures targeting agricultural production were implemented. The experience gained during the response to the 1986 accident at the Chernobyl nuclear power plant was used as a starting point, after which the specific conditions applying to Japanese crops (e.g. rice and soya) and soils were taken into account to adapt the countermeasures. The objectives were the same: to reduce radiation doses to people and the environment. Food with radiocaesium activity concentrations that exceed the action level was not allowed to enter the food distribution system. Compliance with the action levels for food was ensured by an extensive and comprehensive food monitoring programme for foods produced in contaminated areas.

The low action levels applied in Japan led to extensive restrictions on the use of agricultural land, especially in 2012. To produce food below the action levels, it was necessary to remediate some agricultural land [5]. The main types of remediation applied to farmland, applicable to both the Special Decontamination Area evacuated after the accident and the Intensive Contamination Survey Area where people live, depend on the radiocaesium activity concentration (Table 1). Remediation measures for each area of farmland were selected on a case by case basis, taking into account the farmer's opinion. For example, some fruit trees were decontaminated by high pressure washing and whittling (paring shavings from wood) of tree surfaces to remove a major part of the radiocaesium. In other cases, such as the persimmon trees in Date, the choice was not to decontaminate the trees but to remove the upper layer of the land and to support financially the loss of one production year.

In the Intensive Contamination Survey Area, the first decontamination action was to remove topsoil and this affected soil fertility and generated a large amount of waste soil. Alternative measures were then applied to enhance the natural caesium sorption in clay and suppress the transfer of radiocaesium from soil to crops (this was also aided by the addition of fertilizer and potassium to the soil). To ensure that ^{134}Cs and ^{137}Cs in soil used for agricultural production was not artificially enhanced by the addition of fertilizers, an action level of 400 Bq/kg was applied for fertilizers, soil conditioners and compost used to grow seedlings. Moreover, ploughing the soil proved to be as efficient in reducing radiocaesium levels as was soil removal. This approach allowed conservation of the nutrients in the soil and reduction of the amount of contaminated soil waste [5]. Soil removal was considered when the caesium activity concentration was high (Table 1).

The ploughing of many kitchen gardens and orchards soon after the accident contributed to a reduction in the levels of radiocaesium in soils (through the dilution of the upper contaminated layers with deeper uncontaminated soil layers) [5]. Residents of contaminated areas have been allowed to bring locally produced food from their kitchen gardens, freshwater systems or forests to local measuring facilities.

TABLE 1. APPLICABILITY OF REMEDIATION MEASURES TO REDUCE BOTH INTERNAL AND EXTERNAL DOSE FROM UTILIZATION OF FARMLAND IN JAPAN [5]

Applicable techniques	Radiocaesium activity concentration in soil (Bq/kg dry weight)			
	<5000	5000 – 10000	10000 – 25000	>25000
Cultivation with reduced transfer of ^{134}Cs and ^{137}Cs using potassium, fertilizer	X			
Tillage reversal (fields, rice paddies, grassland)	X	X		
Soil suspension in waste and removal with extracted water (rice paddies)		X		
Topsoil removal (fields, rice paddies, grassland)		X	X	
Soil removal using a solidification agent		X	X	X
Weed/grass/pasture removal		X	X	X

4. CONCLUSION

One of the crucial problems related to agricultural production in the contaminated districts is limiting the entry of radionuclides in food products, to reduce the level of exposure as much as reasonably achievable. This issue can be solved by a set of actions to attenuate the migration of radionuclides through the linkages of the biological chain ‘soil to plant’ and ‘plant (forage) to agricultural animals’. For example, in Belarus, practice showed that the introduction of protective measures with proven effectiveness and specific processes in the cultivation of plants reduced the concentration of radionuclides in production (cereals, potatoes, vegetables) by a factor of between 1.5 and 4.0. The introduction of protective measures in livestock (Prussian blue, for example) decreases the radionuclide concentration in milk, meat and eggs by a factor of 3 to 7.

The reorientation of farms in Belarus towards products that do not concentrate radionuclides is another route to reduce the input of radionuclides into the food supply chain. These products generate revenue for the producers and include sectors in meat and dairy farming, pig breeding, or poultry farms. Calculations show that a change in the direction of current production (potato production, cereal production, dairy) to, preferably, beef, pork and bacon, chicken, fatty dairy products (cream, butter, ghee) would reduce the entry of radionuclides into food products by a factor of 1.5 to 2.0, and proportionally reduce internal radiation exposure of consumers. Currently, in all three most affected countries of the former USSR, clean feeding remains an important countermeasure to ensure that meat from intensive farms can be marketed and additional countermeasures are implemented as necessary. For instance, in the Russian Federation, fertilizers are supplied to intensive farms. For private farms, Prussian blue is provided for privately produced milk and, on request, for privately produced meat intended for market [1]. The effectiveness of the different agricultural countermeasures in use on farms in Belarus is summarized in Table 2. The reduction factors (ratio of radiocaesium activity concentration in the product before and after countermeasure application) achieved by each measure are given.

In Fukushima, overall, the comprehensive implementation of food restrictions and monitoring has protected people and improved confidence in farm produce, as reflected to varying extents by the improving market price of some crops.

TABLE 2. EFFICIENCY OF SOME PROTECTIVE MEASURES IN REPUBLIC OF BELARUS [4]

Working method	Efficiency
Combination of the primary and additional cultivation jobs, subsoil tillage (chisel, disk) and minimum cultivation, taking account of the soil type, moistening pattern, application of high-capacity equipment	Reduction of radionuclide accumulation in crops up to 1.3 times
Soil liming	Reduction of radionuclide accumulation in crops by 1.5-3 times
Application of organic fertilizers	Reduction of radionuclide accumulation in crops up to 1.3 times
Application of new forms of slow-acting nitrogen fertilizers	Reduction of radionuclide accumulation up to 1.4 times, nitrates in potatoes, vegetables and feed crops
Application of phosphorus fertilizers	Reduction of Cs-137 accumulation in crops up to 1.5 times, Sr-90 – by 1.2-3.5 times
Application of potash fertilizers	Reduction of Cs-137 accumulation in crops up to 2 times, Sr-90 – up to 1.5 times
Selection of species and varieties of crops with minimum accumulation	Reduction of radionuclide accumulation in crops depending on the plant species up to 30 times, depending on the variety – up to 7 times
Radical improvement of hayfields and pastures	Reduction of radionuclide accumulation in grass stand by 2.5–6 times
Surface improvement of hayfields and pastures	Reduction of radionuclide accumulation in grass stand by 1.5 – 2.9 times
Application of caesium-binding ferrocene-supplemented mixed feed for cattle	Reduction of Cs-137 accumulation in milk and meat by 2-3 times
Special feeding diets for various types of animals with due account to their age and other factors	Reduction of Cs-137 accumulation in milk and meat by 1.5 – 2.5 times

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RADIATION MONITORING OF CONTAMINATED FOODSTUFFS IN POLAND AFTER THE CHERNOBYL ACCIDENT

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Abstract

This paper provides information on the response in Poland to the accident at the Chernobyl nuclear power plant (NPP) in 1986. It provides information on the detection of the radioactive plume which resulted from the accident and passed across Poland, the different levels of radiocaesium contamination levels in foodstuffs, as well as the results of monitoring of radioactive contamination. The last section of the paper explains current arrangements for the radiation monitoring system in Poland.

1. INTRODUCTION

Atmospheric nuclear weapons tests (especially in the beginning of the 1960s) and nuclear accidents such as those at the Chernobyl nuclear power plant in 1986 and the Fukushima Daiichi nuclear power plant in 2011 released radioactive contamination into the environment such as artificial alpha, beta and gamma emitting radionuclides. Most of these radionuclides have practically disappeared from the environment in Poland over the intervening years due to their short half-lives ($T_{1/2}$). For example, residual levels of the caesium radionuclide ^{134}Cs ($T_{1/2}$= 2.06 years) could be detected in the period directly after the Chernobyl accident, but have since decayed and are not found in the agricultural environment. Nevertheless, isotopes with longer half-lives, such as a different isotope of caesium (^{137}Cs, $T_{1/2}$=30.15 years) a radionuclide of strontium (^{90}Sr, $T_{1/2}$=28,78 years), and two radionuclides of plutonium (^{239}Pu, $T_{1/2}$=24110 years and ^{240}Pu, $T_{1/2}$=6563 years) are persistent and may be detected in the environment to this day, although at very low activity concentrations [1].

The nuclear accident which occurred on 26 April 1986 at the Chernobyl nuclear power plant resulted in releases of large amounts of radioactive material into the atmosphere. The material in the atmosphere was carried relatively long distances by the prevailing weather systems and radionuclides were deposited to the ground as the cloud of material gradually dispersed. As a result, food producing environments in Poland and in many other countries in Europe were contaminated with radionuclides.

2. DETECTION OF RADIOACTIVE PLUME

Initially there was an absence of official information concerning the accident. However, measurements at several locations in Poland detected increased radiation dose rates and levels of gamma and beta emitting radionuclides two days after the accident. Data such as these were used to map the trajectories of airborne radioactive material (the radioactive plume) as it passed across the country [2]. As these air masses contaminated with radionuclides passed over the territory of Poland, deposition occurred leaving enhanced levels of radioactivity on the ground, especially in regions that experienced rain. The highest levels of residual radionuclides were detected in the northern part of Poland.

3. INTERVENTION MEASURES TAKEN IN POLAND

After the accident, the only intervention measure taken in Poland was the distribution of stable iodine (Lugol's iodine). Ingestion of stable (non-radioactive) iodine is used to block the uptake of radioiodine into the body, particularly the thyroid gland. The thyroid gland is at particular risk from irradiation from radioactive iodine because the thyroid uses iodine to produce hormones that regulate the body's metabolism. The thyroid gland does not differentiate between stable and radioactive iodine. Therefore, stable iodine taken before or at the beginning of an exposure to radioactive iodine ensures that the thyroid is fully loaded with non-radio active iodine and blocks the uptake of radioactive iodine thus reducing internal radiation exposure of the thyroid. Although it was decided that there was no need to withdraw food products from the market, strengthening and expanding radiological monitoring of food was one of the utmost importance to measure and monitor the situation.

4. RADIATION MONITORING OF FOODSTUFFS OVER THE YEARS

Dairy products and cow milk in particular are important nutritional sources (especially milk for infants) and activity concentrations of radiocaesium and radio iodine were measured for several years post-accident (Fig. 1). Other foodstuffs in Poland were also monitored . The focus of the monitoring progrmmes was the specific activity concentrations of radiostrontium, radio iodine and radio caesium (for instance ^{90}Sr, ^{131}I, ^{134}Cs and ^{137}Cs in mushrooms, vegetables, fruits, meat and milk) after the accident and monitoring any changes over time.

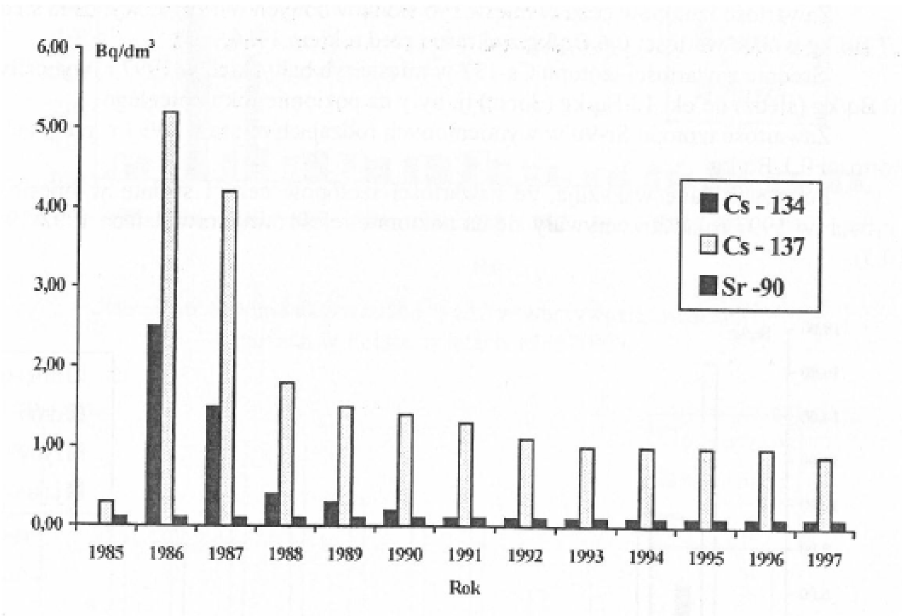

FIG. 1. Average yearly activity of ^{134}Cs, ^{137}Cs and ^{90}Sr in milk in Poland between 1985 and 1997 [3].

5. CURRENT SITUATION

The national radiological monitoring programme was updated in 2000 and currently consists of systematic measurements of gamma radiation dose rates at given points within the territory of Poland; measurements of radionuclides in the environment; and; radionuclides in foodstuffs. The objectives of the measurements are to:

— Assess the national radiation situation and assess radiation hazards to the public during a radiation emergency and under normal conditions.
— Examine long term changes of the environment and radioactivity in food.
— Forecast consequences caused by the contamination of the environment by radioactive substances and take possible preventive measures.
— Early detection and warning regarding an increase in the dose rate and radioactive contamination in the environment in order to take suitable measures and comply with provisions of conventions and bilateral agreements on early notification of nuclear accidents

The monitoring network comprises basic and subsidiary monitoring stations. The network of basic monitoring stations throughout Poland include automatic permanent monitoring stations, ASS-500 stations aerosol sampling stations (ASS-500 stations), and monitoring stations of the Institute of Meteorology and Water Management (IMWM). Subsidiary stations include monitoring stations of the Ministry of National Defence, located at military establishments.

Poland is also implementing its strategy to increase its national radiation monitoring system.

The Regulation of the Council of Ministers contains a list of early warning stations for radioactive contamination, and units conducting measurements of radioactive contamination have been operating since 1 January 2003. This legislation also specifies in detail the tasks of these stations. Monitoring is conducted by:

- Measurement stations, which make up an early warning network for radioactive contamination.
- Measurement units, which conduct measurements of radioactive contamination relating to environmental materials and foodstuffs.
- Specialized units of research and development entities within universities and other institutions [4].

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REMEDIATION STRATEGIES FOR RADIOACTIVE CONTAMINATION OF AGRICULTURAL ENVIRONMENT FOR FOOD SAFETY IN PAKISTAN

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Abstract

The Chernobyl nuclear power plant accident resulted in an increase of radioactive contamination at a global level. Interim International Radionuclide Action Levels for Food (IRALF) were introduced in 1985. To avoid undesirable exposure to the public, Pakistan imposed maximum radionuclide contamination levels on food items. Measurements of various radionuclides in various imported and exported food items were carried out at an environmental laboratory with modern counting systems capable of detecting low levels of radionuclides. Since 1956, Pakistan has been benefiting from the use of nuclear related technologies for the advancement of agriculture, engineering, biology, and medicine. The Pakistan Atomic Energy Commission (PAEC) was established as a research institution and government authority focused on peaceful uses of nuclear technology. In 2001, the Pakistan Nuclear Regulatory Authority (PNRA) was established as an independent body for the regulation of nuclear safety, radiation protection, transport and waste safety in the country. The PAEC is responsible for design preparation and proper operational functions of commercial nuclear power plants. The safety regulations and protection of nuclear power facilities are managed by PNRA. Pakistan is in the process of building power plants with a capacity of ~8800 MW by 2030. Under this policy, the Karachi Nuclear Power Plant (KANUPP) and Chashma Nuclear Power Plant (CHASHNUPP) have been expanded under PAEC and PNRA programmes. The Nuclear Institute for Food and Agriculture (NIFA) in Peshawar is a research institute under the PAEC and conducts research and development in the nuclear sciences related to food irradiation, crop production and protection, soil fertility, water management and conservation and adding value to food resources. In addition, the Food and Environmental Section at NIFA is working to assess radioactive contamination in water, soil and agricultural produce, and plan strategies in case of a nuclear accident. The Fukushima Daiichi accident in March 2011 did not directly affect land in Pakistan. However, Pakistan is designing strategies to deal with contaminated territory as part of emergency preparedness and planning.

1. INTRODUCTION

Since its establishment in 1956, the Pakistan Atomic Energy Commission (PAEC) has promoted nuclear technologies for the advancement of agriculture, engineering, biology, and medicine [1]. Currently, PAEC is responsible for design preparation and proper operational function of commercial nuclear power plants. The safety regulations and protections of the nuclear power facilities are managed by the Pakistan Nuclear Regulatory Authority (PNRA) [2].

2. IMPORTANCE OF AGRICULTURE AND POPULATION

Agriculture is an extremely important sector of Pakistan's economy. It plays a vital role as the foundation for economic development and growth in this country (Fig. 1). Agriculture contributes more than 21% to Gross Domestic Product (GDP) and provides employment to 45% of the total labour force of the country. Agriculture provides raw material to the industrial and manufacturing sector and agricultural communities are also significant markets for industrial products. Food production is important, Pakistan is one of the world's largest producers and suppliers of different food commodities, i.e. chickpea, rice, mango, cotton, milk, date palm, sugarcane, apricot, kinnow, mandarin oranges, clementines, onions and wheat [3].

Currently, the population of Pakistan is estimated at approximately 200 million people, in contrast Pakistan had a population of 45.9 million people in 1960. It is one of the top ten most populated countries in the world today and the people of Pakistan represent 2.56% of the world´s total population.

FIG. 1. Provinces of Pakistan and their agriculture importance (courtesy of the Pakistan Trading Economics [3]).

3. PAKISTAN NUCLEAR PROGRAMME

Since it was established, PAEC has overseen the extensive development of nuclear infrastructure to support the economic uplift of the country, for example by founding institutions that focus on the development of food irradiation and of nuclear medicine and radiation therapy for cancer treatment. In 1964, PAEC [1] established its first research institute, the Pakistan Institute of Nuclear Science and Technology (PINSTECH) at Islamabad.

In 1965, the PAEC reached an agreement with Canadian General Electric to build a CANDU reactor in Karachi. Building work commenced in 1966 and in 1971 construction was completed on Pakistan's first nuclear power plant, the Karachi Nuclear Power Plant (KANUPP). Since that time Pakistan has several nuclear reactors in operation and under construction. Providing policy guidance to the Government, PAEC's studies envision setting up power plants for energy production with a capacity of ~8800 MW by 2030. Under this policy, more units are under construction at the KANUPP and Chashma Nuclear Power Plant (CHASHNUPP) under the supervision of PAEC and PNRA (Table 1).

In addition to power generation, PAEC's research has focused on the development of nuclear related technologies for other peaceful purposes. For example, the PAEC research centres current include four in the agricultural sciences: the Nuclear Institute for Food and Agriculture (NIFA), Peshawar; Nuclear Institute of Agriculture (NIA), Tandojam; Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad and the National Institute of Biotechnology and Genetic Engineering (NIBGE), Faisalabad. Of these four institutes, NIFA is the only one in Pakistan conducting R&D on Food Safety [4].

TABLE 1. SUMMARY OF NUCLEAR POWER PLANTS IN PAKISTAN [1]

Name/type	MW	Status
Research reactors — PINSTECH PARR-1 — Utilize low enriched uranium PARR-2 — Utilize high enriched uranium	 10 0	 Research Research
Karachi Nuclear Power Plant (KANUPP) —K-1	137 MW	Operating safely for >40 years; 1st NPP
Chashma Nuclear Power Plant (CHASHNUPP) (PWR) — C-1 and C-2	2 × 325 MW	Operational
CHASHNUPP (PWR) — C-3 and C-4 with a design life of 40 years.	2 × 340 MW	C-3 recently operating C-4 under construction
KANUPP (PWR) — K-2 and K-3	2 × 1100 MW	Ground breaking performed in Nov. 2013

4. NUCLEAR REGULATORY BODY

The nuclear regulatory infrastructure [2] has been in place since 1965, when the first research reactor, PARR-I, was commissioned. The nuclear regulatory regime further improved when the first nuclear power plant was commissioned in 1971 at Karachi. A nuclear safety and licensing division was established at PAEC HQ which functioned as the regulatory body until it was upgraded to the Directorate of Nuclear Safety and Radiation Protection (DNSRP) after the promulgation of the Pakistan

Nuclear Safety and Radiation Protection Ordinance 1984. Pakistan signed the Convention on Nuclear Safety in 1994, as a result of which it became obligatory on the part of the Government of Pakistan to establish an independent nuclear regulatory body. Complete separation of promotion and regulatory functions and responsibilities was achieved in 2001, when the President of Pakistan promulgated the Pakistan Nuclear Regulatory Authority (PNRA) Ordinance. PNRA was empowered to determine the extent of civil liability for damage resulting from any nuclear incident.

4.1. Lessons learned from the Chernobyl and Fukushima Daiichi accidents

The Chernobyl accident of 26 April 1986 was the worst disaster in the history of the peaceful applications of nuclear energy. Interim International Radionuclide Action Levels for Food (IRALF) were introduced at an expert meeting organized at FAO Headquarters, in Rome in December 1985 [5]. To avoid undesirable exposure to the public, Pakistan, like other countries, implemented maximum levels of radioactive contamination on food items [6].

In Pakistan, a laboratory at PINSTECH can detect low levels of radionuclides in environmental samples using modern gamma spectroscopy and counting systems to measure various radionuclides that may be present in trace quantities in various imported/exported food items [8]. Samples are analysed on a routine basis around nuclear installations, as are samples from the nationwide network for air monitoring samples. The laboratory capabilities in gamma spectrometric analysis of environmental samples are given in Table 2.

5. CONCLUSION

The knowledge and experience gained from dealing with radionuclides in food and agriculture after the Chernobyl and Fukushima accidents indicates that the appropriate selection and implementation of decontamination methods can significantly reduce levels of radionuclides in cultivated land.

Studies into cost and effectiveness of decontamination strategies adopted in radiation contaminated areas (e.g. in Fukushima Prefecture with regard to reducing radionuclide levels in soils and reducing external radiation dose rates) are also helpful to emergency preparedness and response planning in countries like Pakistan.

In the case of a nuclear accident in Pakistan, population data and data relating to agricultural produce will be used to assess costs and effectiveness when planning measures to avert public exposure to radiation (reduce doses) in any area affected with contamination.

Guidelines for remediation strategies to reduce the radiological consequences of environmental contamination, such as IAEA Technical Reports Series No. 475, would also be helpful in the event of an emergency situation in Pakistan.

Decontamination strategies should be determined according to air dose rate measurements and future land-use plans.

An advanced approach for deriving remediation strategies for contaminated territory and remedial actions necessary to reduce annual exposures below 1 mSv should be developed.

Every effort should be made to reduce undue exposure to radiation and this should not neglect internal exposure from low levels of radionuclides in foods that although low-level may be consumed over a long period of time.

TABLE 2. GAMMA SPECTROMETRIC ANALYSIS OF ENVIRONMENTAL SAMPLES

No.	Nature of sample	Frequency	Size/ volume	Collection method	Technique of analysis
1	Airborne particulates	Continuous (Filter/week)	67000 m^3 of air	Filtration (polystyrene filter)	Computer based high resolution Ge (Li) gamma spectrometry
2	Seasonal vegetables	Biannual	5 kg	From local market	NaI (T1) Scintillation gamma spectrometry (after ashing)
3	Meat, poultry fish	Biannual	3−4 kg	From local market	NaI (T1) Scintillation gamma spectrometry (after ashing)
4	Wheat	Annual	1−2 kg	Suburban localities	NaI (T1) Scintillation gamma spectrometry (after ashing)
5	Prepared meal	Monthly	2 meals	From Cafeteria	NaI (T1) Scintillation gamma spectrometry (after ashing)

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SOCIOECONOMIC ASPECTS

(Technical Session 5)

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CURRENT SITUATION AND PAST CONDITIONS IN THE DISASTER AREA

Challenges going forward in the reconstruction of agriculture in Fukushima

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Abstract

As a consequence of the 2011 earthquake and tsunami in Japan and the accident at the Tokyo Electric Power Company Fukushima Daiichi nuclear power plant, the residents who lived within what was designated as the planned evacuation zone were forced to move away, dramatically changing their lives ever since. Each municipality implemented evacuation countermeasures in its own way. Evacuation centres and relocated branches of local government administrative offices were established in the neighbouring cities of Fukushima, Koriyama, Date and Iwaki. Including those who left independently, close to 100 000 people relocated to live in other areas, these evacuees are spread all over Japan. Immediately after the accident, residents were worried about the health effects of radiation and the implications for their future, such as where to live permanently after the evacuation centres were no longer necessary. With the passage of time, the problems they have faced have also changed. As a result of the decontamination process, large quantities of wastes have been produced, for example soil and scrapings from the surface of affected land. These wastes have been packed into containers and are kept in storage areas that are maintained on leasehold land in various locations. However, once the residents returned home, the sight of these containers at the storage areas was a source of stress for them, something they did not feel when they were living at the site they where they were evacuated. Maintaining agricultural land after decontamination has been another serious problem. For example, in Naraha town, 20 farmers returned to resume farming/cultivation in a land area of about 700 ha. However, it was impossible for all of them to engage in cultivation as only a limited area was available for production. Without proper maintenance and management, decontaminated land may turn into weed infested farmland and could fall out of production.

1. INTRODUCTION

As a consequence of the 2011 earthquake and tsunami in Japan and the accident at the Tokyo Electric Power Company Fukushima Daiichi nuclear power plant, the residents who lived within what was designated as the planned evacuation zone were forced to move away, dramatically changing their lives. Each municipality implemented evacuation countermeasures in its own way. Evacuation centres and relocated branches of local government administration offices were established in the neighbouring cities of Fukushima, Koriyama, Date and Iwaki. Approximately 100 000 people were evacuated or were relocated, including residents who left independently.

Immediately after the accident, residents were worried about the health effects of radiation and the implications for their future. For example, where to live once they had left the temporary evacuation centres. With the passage of time, the problems they have faced have also changed. An example of a later cause for anxiety relates to wastes stored at temporary locations in the decontaminated areas. Decontamination activities have resulted in large quantities of wastes and these have been packaged in containers and stored on leasehold land in various locations. Once residents returned home the sight of piles of these containers was a source of stress for them, something they did not feel when they were living at the evacuation centres.

Maintaining agricultural land after decontamination has been another serious problem. For example, in Naraha town, 20 farmers returned to resume farming and horticulture in a land area of about 700 ha. However, it was impossible for all of them to engage in cultivation activities because only a limited area was available for production. Without proper maintenance and management, decontaminated farmland may turn into weed infested land.

2. COMMUNICATION

After the nuclear power plant accident caused by the Great East Japan Earthquake on 11 March 2011, residents living in the designated planned evacuation area were forced to move from the area to live somewhere else. The method of evacuation was dependent on each local government; most of the residents were evacuated to relatively large cities nearby, i.e. Fukushima, Koriyama, Date and Iwaki.

Local governments and municipalities resumed their administrative services to the residents at branch or temporary offices. Some of these services managed to move back to the original or main office, but it was still difficult for staff in different locations to coordinate their activities and maintain smooth administration. It should be remembered that staff of the local governments responsible for supporting victims were themselves victims of the disaster.

FIG.1. The explanatory meeting for residents at Iitate-village, Fukushima.

Immediately after the accident, the vast amount of information dealing with the evacuation as well as the environmental pollution caused by radioactive substances, delayed evacuation efforts in each municipality (Fig. 1). This resulted in a serious lack of the trust between residents and the local and national governments. It also confused residents regarding the evacuation process and safety at the evacuation sites.

It has been more than five years since the accident and with the evacuees in danger of becoming long term evacuees, their problems have also changed to those of the long term displaced. More attention needs to be paid to this issue.

Research by national and local governments, research organizations, universities, and the private sector on decontaminating farmland and mitigating damage to agriculture and caused by environment pollution should be carried out locally and targeted at local producers. However, many such well-intentioned actions have proved to be a burden rather than a positive contribution to the local governments and residents of the stricken areas. At Iitate-village in Fukushima, many organizations conducted research, but failed to take into account the views of residents and obtain the cooperation of the local government in order to achieve their goals. Efforts should be made to help residents understand what is being done so that research activity supports the local government. To this end, I was sent to the Iitate-village from a research organization under the jurisdiction of the Ministry of Agriculture, Forestry and Fisheries.

3. CHANGING PROBLEMS

Engaging with the local government and residents as a representative of the National Agriculture and Food Research Organization has made it easier to exchange information, to explain why field surveys are necessary and to make sure that appropriate land is selected and surveyed. It has made studies and research activities more effective through better cooperation with local government and residents. However, the role of such a coordinator, representing a national organization, is a demanding one. Many issues are concentrated onto one person and it involves working with many different local groups. These groups have included the local assembly, agricultural committees, resident groups and other groups related to the agriculture, forestry and fisheries industries. This work is in addition to the duties relating to decontamination technologies and other organizations. Although demanding, having the same person in this role for a long period of time builds trust between the different organizations/groups concerned and the national government. It also helps foster more effective cooperation with local residents.

The local governments also faced challenges in their efforts to support residents, fulfil their duties and restore daily services to the suffering residents. The pressures on local government is considerable and it has been suggested by some that national government should not only start new businesses or conduct studies, but also support local government activities more directly.

The issue of risk to health from radioactive material is an obstacle in achieving the reconstruction and regeneration of agricultural production. Radioactive substances have been found in agricultural products, and there has been external and internal exposure to farmers. Reducing the levels of these radioactive substances is thus an urgent task. Therefore, it is necessary to collect data on the contamination of farmland or on products over a wide area. To restore agriculture in the stricken areas, efforts are now focused on decontamination measures for farmland soil and mitigation measures to remove radioactive substances from agricultural produce. These measures are summarized in A Guidebook of Decontamination issued by the Ministry of Agriculture, Forestry and Fisheries, and the Decontamination Guidelines issued by the Ministry of the Environment for use by local governments when they decontaminate. In addition, collaborative investigations between prefectures as well as research and technology developments for decontamination have been published in the technical literature, but local residents are not necessarily aware of this information.

4. ACCURATE DISCLOSURE OF INFORMATION

Producing clear and accurate information is necessary because it is important to be fully informed in order to implement decontamination technology and techniques as a series of systems, depending on the practical situation. It is also necessary for the local government to make these technologies and techniques available for the residents to access and use. The Ministry of Agriculture, Forestry and Fisheries has expanded the use of measures and technologies to reduce radiocaesium levels in rice and has widened them in scope to include other crops. Repeated surveys and monitoring for radiocaesium in the agricultural environment, technical assessments by specialists and coordination with local residents is critical to remediation and restoring agricultural production. Providing accurate information in a way that can easily be understood by those who need it at the local level is a key step to the mitigation of enhanced levels of radiocaesium in agricultural lands.

Many local government bodies and residents returned in April 2017. Most of the returnees are elderly people, and they have doubts regarding the local administrative services. Restoring agricultural production to the area is not only related to implementing decontamination techniques but it also involves other local issues such as confidence in administrative services and appealing to younger generations to return and live in these communities. Restoring agricultural production in Fukushima is requiring more focus on the practical realities faced by residents.

CHERNOBYL: SOCIOECONOMIC AND ENVIRONMENTAL IMPACTS AND PROSPECTS

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Abstract

In the context of the UN-wide action plan for Chernobyl recovery, the IAEA has contributed through its technical cooperation programme to mitigate socioeconomic and environmental impacts of the accident in the areas of forest management, agriculture, food security and cancer treatment.

1. INTRODUCTION

The accident at the Chernobyl nuclear plant in April 1986 caused widespread radioactive contamination in many regions of Belarus, the Russian Federation and Ukraine. Massive radioactive contamination forced the evacuation of more than 100 000 people from the affected region during 1986, and the relocation, after 1986, of another 200 000 from Belarus, the Russian Federation and Ukraine. Some five million people continue to live in areas contaminated by the accident and have to deal with its environmental, health, social and economic consequences. The national governments of the three affected countries, supported by international organizations, have undertaken costly efforts to remedy contamination provide medical services and restore the region's social and economic well-being.

The years 2006–2016 are the Decade of Recovery and Sustainable Development of the Affected Regions (as proclaimed by the UN General Assembly). The resolution requested UN agencies to coordinate their efforts and welcomed the preparation of a UN-wide 'Action Plan' for Chernobyl recovery. The IAEA has participated in the design and implementation of this action plan, which aims to overcome some of the existing human and socioeconomic consequences of the catastrophe and for decades to come.

2. CONTRIBUTION OF THE IAEA TECHNICAL COOPERATION PROGRAMME

The IAEA has contributed to the mitigation of the socioeconomic and environmental consequences of the Chernobyl accident through its technical cooperation programme[1] in the following four areas:

— Enhancing capacity of Belarusian authorities and enterprises for optimal forest management in areas affected by the Chernobyl accident, as well as of local and national organizations in the establishment of radiological monitoring measures and decreasing radiation risk from contaminated forests in forested areas of Belarus affected by the Chernobyl accident; increased efficiency in decision making on the use of contaminated forested lands for economic purposes, which were substantially extended.
— Improving capacity to use environmentally sound agricultural remediation technologies in areas affected by the Chernobyl accident; this contributes to an increase in the economic effectiveness of animal farms located in the contaminated regions and to improved quality of drinking water and, overall, the health of the population drinking this water.
— Improving capacity to prevent selected radionuclides from entering the food chain, thereby contributing to the safe living and well-being of the population of the radioactively contaminated territories; in particular, training and expert guidance provided to improve capabilities to assess the distribution of plutonium and americium-241 isotopes in components of the exclusion zone ecosystem, and prevent their entry into agricultural products produced in the territories adjacent to the exclusion zone.
— Improving capacity of radiotherapy services for the treatment of cancer through the introduction of modern techniques in radiotherapy for oncological patients in the Chernobyl affected territories.

[1] Unpublished project documents and reports from the IAEA Technical Cooperation Programme.

FARM HOUSEHOLD JOB STRUCTURE AND RESTORATION OF FARMING IN KAWAMATA TOWN

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Abstract

To restore a situation, it is first necessary to ascertain a point of reference to the original circumstances. It was therefore necessary to clarify the farmers' work organization and the structure of their farming before the nuclear accident, so that this information could be used as the 'benchmark' for restructuring farming in villages affected by the accident. Hence, interviews were conducted with people who were evacuated from a 'zone in preparation for the lifting of the evacuation order' in Kawamata town, Fukushima Prefecture. The objectives were to clarify rural and farming job structures and ascertain a course of action to restart/restore farming. Research identified the following general findings: most males of breadwinner age (i.e. old enough to earn money to support their family) are full time employees of companies and their wages match with average family expenditures; farming is generally undertaken by the older (retired) generation and for maintaining family farms that are assets; the only full time commercial farmers identified were tobacco growers, dairy farmers and floriculture growers; the number of full time males farming who are family breadwinners is very small; mostly farmers are of retirement age (which is about 60 years in Japan). Therefore, to restart/restore farming in this location, full time farmers are the primary actors and farmers of retirement age are supporting actors.

1. INTRODUCTION

Restructuring farming in villages requires an understanding of their historical development and the current farming and non-farming job situation. Our research in this area will include many economic studies, such as local economic history, job structures and wages, differences in income (e.g. generational and gender differences). These different aspects need to be included because we are applying the first analysis of the former rural economic situation. Much of the research is ongoing, however, research has been concluded on job structures in a 'zone in preparation for the lifting of the evacuation order' in Kawamata town. The objectives of the paper are to report on recent findings regarding the case study of Kawamata town, Fukushima Prefecture, specifically the clarification of farming job structures and a way to restart/restore farming in this community. Interviews were conducted with evacuated farmers from Kawabata town (Yamakiya area), focusing on farming engagement and non-farming jobs in each household and how these cover family expenses. The results of the interview are summarized in Table 1.

2. TYPES OF FARMERS

Kawamata town is in a mountainous area neighbouring Fukushima city. The town is served by a network of highways and the area has been industrialized since the period of high economic growth in Japan in the 1960s and 1970s. Historically, Kawamata town was known as a silk producing area. Each farm household grew mulberry in small upland fields and produced silk for cash revenue, growing rice for their own consumption. They kept this style of living until the 1970s, then switched from silk and mulberry production to tobacco farming and part-time non-farming jobs. At first, part time jobs were in the construction industry based in Tokyo, but since the mid-1970s, full time factory jobs became standard for males. Tobacco is a main cash crop in town, with farm size being defined by the size of the inheritance, which kept farms small i.e., in Table 1, the area of the largest tobacco farm is only 150 ares (one are is equal to 100 m^2). Table 1 illustrates that most farmers are above the age of 60. This generation has earned household income through non-farming, full time jobs and tobacco cultivation, and they are close to retirement, but kept the job structure until the evacuation. However, floriculture includes young male farmers, such as farmer number 2, because greenhouse floriculture is profitable, and they expand their farm size continuously. Although several young males have become full time farmers, pursuing floriculture and greenhouse strawberry production, farming is mostly a job undertaken by retired people.

The female tobacco growers listed in Table 1 are housewives who manage their fields and earn cash revenue for covering family expenses, while the female rice farmers are wives that cultivate the field for self-consumption. The combination of farming wives and husbands with non-farming full time jobs is standard among generations above 60 years of age. However, for the younger generations, males and females are both engaging in non-farming full time jobs, except for full time farmers such as farmer number 2. The younger generations (i.e. aged 40–50 years old), who have non-farming full time jobs do not engage in farming at all, since they do not need farming to cover their family expenses.

TABLE 1. TYPES OF FARMERS (*Source: Interviews (2014–2015)*)

Type	Number	Crop (Unit: a)			Main Farming Family Member			Q: Will you restart farming ?
		Rice	Tobacco	Others	Sex	Age	Former Non-Farming Jobs	
Floriculture	1	180		Flower	Female	62		Yes
	2	99		Flower	Male	40	Full-time	Yes
	3	100		Flower	Male	70	Full-time	Yes
	4	60		Flower	Male	70		Yes
	5	60		Flower	Male	83	Full-time	No
	6	16		Flower	Female	80		Yes
	7	100		Flower	Male	53	Own business	Yes
Tobacco	8	110	150		Male	63		Yes
	9		80		Male	88		No
	10	130	50		Male	81	Full-time	No
	11	50	80		Male	80		Yes
	12	120	50		Male	65	Full-time	Yes
Rice	13	250			Male	67	Full-time	No
	14	40			Female	84		No
	15	40			Female	80		Yes
Non-farmer	16				Female	87		No
	17				Male	60	Full-time	No
	18				Male	80	Full-time	
	19				Male	70	Own business	
	20				Male	63	Full-time	

3. NON-FARMING JOBS AND WAGES

Nonaka [1] indicates that the typical wage level for males in their 40s to their 60s is not enough to cover their family expenses in the North Tohoku region. As this is a result of poor job opportunities, they need to engage in farming to cover expenses. Figure 1 indicates male annual wages for non-farming jobs in the town, showing different characteristics from the North Tohoku region as per the study of Nonaka [1].

Figure 1 indicates a general tendency for wages to increase by age, a typical feature of the wage system in Japan, with wages reaching a maximum of around JPY 5 million. According to our interviews at the job centre in Fukushima Prefecture, respondents indicated that job opportunities in factories are numerous around Fukushima city, with wage levels close to the ones in the suburbs of Tokyo. The non-farming jobs referred to in Figure 1 are mostly automobile industry related and the wage level is close to that found in urban areas, as per Nonaka [1]. As such, those aged 40 to 60 reach the JPY 5 million wage level, which covers average family expenses; in such cases, their families do not need to farm to supplement their income. Moreover, many spouses also have full-time non farming jobs with wages around JPY 1 million.

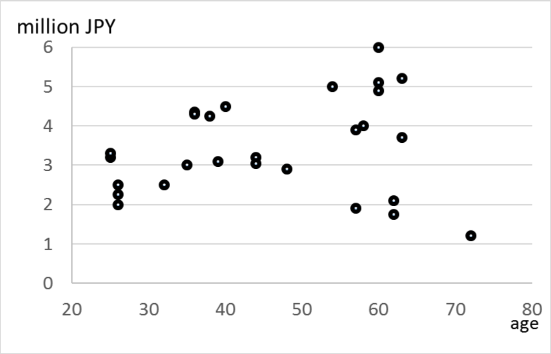

FIG. 1. Wage level of male non-farming jobs. Source: Interviews (2014–2015).

4. PART-TIME FARMERS

In our interviews, around 40% of farm households answered “no” to whether they would restart farming as in 2013, and the local government expects the rate to further decrease. The government funded and arranged for farmland surface soil to be replaced, a method to reduce farm land radioactivity. This process is finished, the new soil is now being treated with compost and fertilizer. After fertilizing, government employed workers must weed farmland until the evacuated farmers return. The government offers farmers a contract fee for weeding their farm land as part of restoring farming; only 30% of farmers accepted this offer. However, full-time farmers aged 30 to 55 organized farming groups and signed contracts with the other 70% of farmers to attend to their land up to their return. The possibility of contracted farm land being rented by the farming group is high; in this case, the farming group would accumulate around 70% of the town’s farm land.

5. CONCLUSION

The nuclear accident created significant problems for farmers, they were mostly discouraged from farming. However, the reduction in the number of farmers over time is determined by the job structure generational gap. This indicates that those who persist as full time farmers in the farming group would accumulate most farm land, and young full time famers in floriculture would expand the size of their businesses. As previously mentioned, females in the younger generations have full time non-farming jobs, but their wages tend to be around JPY 1 million. However, the floriculture group in Kawamata has female managers with significantly higher incomes, making younger generation females ideal candidates for full time floriculture farming.

ACKNOWLEDGEMENT

This research was funded by MAFF, 'Sentan-Jigyou Fukushima'.

REFERENCE

[1] NONAKA, A., An Overview of studies of the low non-farming wage problem in the rural labor market in Japan, Jpn. J. Rural Econ. **11** (2009) 33–46.

CLOSING SESSION

Chairperson

T. SHINANO
National Agriculture and Food Research Organization

CLOSING REMARKS

T. Imbe
President,
National Agriculture and Food Research Organization,
Japan

On behalf of the National Agriculture and Food Research Organization (NARO), I would like to express again my sincere appreciation and gratitude to the FAO and IAEA for joint sponsorship of this technical workshop on Remediation of Radioactive Contamination in Agriculture. I would also like to thank all the speakers for very impressive and meaningful presentations, and all the participants for earnest discussions on how to recover from a radiation disaster that affects agriculture.

The damage caused by the Great East Japan Earthquake and the accident at the Fukushima Daiichi nuclear power plant was enormous, but with the cooperation of farmers, researchers, engineers, and residents in the affected areas, steady progress has been achieved in our reconstruction and revitalization efforts. On this occasion, I would like to commend all the people involved in the recovery of agriculture in affected areas especially the farmers who have cooperated with various research organizations, so that agricultural activities can be revived as soon as possible.

During the last two days of this workshop, we have learned a great deal about radioactive contamination in agriculture. Experience with Chernobyl and our experience in Fukushima were shared among all the participants. All the presentations and discussions are very helpful for us. After going back to Japan, we will continue our efforts to pursue research on remediation and recovery of agriculture in Fukushima.

I believe that nuclear accidents such as at Fukushima Daiichi must never be allowed to happen again. However, it is also important to share our experience. The studies presented in this workshop will serve particularly as reference information for future generations and will help them in dealing with all the challenges associated with the effects of the nuclear accident.

I am also glad to announce that the joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture and NARO have signed ‘Practical Arrangements’ between the two institutions, so that we can work more closely in pursuing research towards reconstruction and revitalization of agriculture in areas affected by the nuclear accident. I wish we can start collaborative projects as soon as possible. NARO will continue the project for remediation of farmland and recovery of agriculture in Fukushima in the next five years as part of its basic plan for agriculture.

Five years from now, I hope we can organize the next workshop. And it should be in Fukushima. I hope to see all of you then. Lastly, I would like to express my appreciation to the FAO/IAEA and NARO staff for a very well organized workshop. Thank you very much everyone.

ABBREVIATIONS

ANOVA	analysis of variance
DNSRP	Directorate of Nuclear Safety and Radiation Protection
F1NPP	Fukushima Daiichi Nuclear Power Plant
GDP	gross domestic product
GIS	Geographical Information System
IMWM	Institute of Meteorology and Water Management
IRALF	Interim International Radionuclide Action Levels for Food
KANUPP	Karachi Nuclear Power Plant
KSB	potassium solubilizing bacteria
MAFF	Ministry of Agriculture Forestry and Fisheries
MEXT	Ministry of Education, Culture, Sports, Science and Technology
NARO	National Agriculture and Food Research Organization
NIFA	Nuclear Institute for Food and Agriculture
PINSTECH	Pakistan Institute of Nuclear Science and Technology
PL	permissible levels
RASSC	Radiation Safety Standards Committee (IAEA)
RIP	radiocaesium interception potential
SRC	short rotation coppice
TEPCO	Tokyo Electric Power Company
TPL	temporary permissible level
TUAT	Tokyo University of Agriculture and Technology

Appendix I

TECHNICAL WORKSHOP

FAO/IAEA–NARO Technical Workshop on Remediation of Radioactive Contamination in Agriculture

Meeting Room C1, C Building
IAEA Headquarters, Vienna, Austria
17–18 October 2016

PROGRAMME

Monday, 17 October 2016

Time	Activity	Speakers
09:00–09:20	**Opening Session** Chair: Mr Zhihua Ye Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture International Atomic Energy Agency	
09:00–09:05	Opening remarks	Mr Zhihua Ye
09:05–09:10	Welcome and Opening Statement	Mr Aldo Malavasi Deputy Director General, Department of Nuclear Sciences and Applications International Atomic Energy Agency
09:10–09:15	Opening Statement	Mr Qu Liang Director, Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture International Atomic Energy Agency
09:15–9:20	Opening Statement	Mr Tokio Imbe President, National Agriculture and Food Research Organization, Japan
09:20–10:20	**Plenary Session** Chair: Mr Zhihua Ye	
09:20–09:40	Plenary 1: Technical overview of key agricultural events since the nuclear power plant accident in 2011	Mr Nobuhisa Koga Kyusyu Okinawa Agricultural Research Center National Agriculture and Food Research Organization, Japan
09:40–10:00	Plenary 2: Main highlights on Chernobyl over 30 years and current situation	Ms Brenda Howard Centre for Ecology & Hydrology, Lancaster Environment Centre, UK
10:00–10:10	Plenary 3: Farmer's experience	Mr Katsunobu Honda Farmer of Kawamata town, Fukushima, Japan (English interpretation by NARO staff)
10:10–10:20	Plenary 4: Joint FAO/IAEA initiatives on radionuclides in food and agriculture	Mr Gerd Dercon Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture International Atomic Energy Agency
10:20–10:30	Questions and answers	All
10:30–11:00	**Coffee break**	

Time	Activity	Speakers
11:00–12:30	**Technical Session 1** **AGRICULTURE LAND AND WATER** Chair: Mr Gerd Dercon Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture International Atomic Energy Agency	
11:00–11:20	1.1 Dynamics of radioactive caesium in agro-environment	Ms Noriko Yamaguchi Institute for Agro-Environmental Sciences, National Agriculture and Food Research Organization, Japan
11:20–11:40	1.2 National experience in remediation of contaminated farmlands after the Chernobyl accident	Mr Valerii Kashparov National University of Life and Environmental Sciences, Ukraine
11:40–12:00	1.3 Development of physical topsoil removal techniques and machines for farmland decontamination	Mr Sumihiko Miyahara Institute of Agricultural Machinery, National Agriculture and Food Research Organization, Japan
12:00–12:20	1.4. Integrated approaches for a better understanding and modelling of radionuclides transfers along the soil-soil solution plant continuum	Ms Pascale Henner Institute of Radio-protection and Nuclear Safety, France
12:20–12:30	Discussion and closing remarks	All
12:30–13:30	**Lunch break**	
13:30–15:00	**Technical Session 2** **PLANTS AND CROP PRODUCTS** Chair: Mr Stephan Nielen Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture International Atomic Energy Agency	
13:30–13:50	2.1 Mitigation of radioactive caesium transfer from soil to plant	Mr Takuro Shinano Tohoku Agricultural Research Center, National Agriculture and Food Research Organization, Japan
13:50–14:10	2.2 Phyto-management of contaminated land: science, technology and context	Ms Hildegarde Vandenhove Belgian Nuclear Research Centre - Institute for Environment Health and Safety, Belgium
14:10–14:30	2.3 DEMETERRES, A collaborative project for the remediation of agronomic soils contaminated with caesium	Mr Alain Vavasseur French Alternative Energies and Atomic Energy Commission (CEA), France
14:30–14:40	2.4 Growth and radiocaesium accumulation of *Brassica rapa L. var*. perviridis grown in three different caesium-contaminated Fukushima soils as influenced by potassium solubilizing bacteria inoculation	Mr Roland Rallos Philippine Nuclear Research Institute, Philippines
14:40–14:50	2.5 Physiology of Cs uptake by rice	Mr Shinichiro Uematsu Belgian Nuclear Research Center (SCK-CEN), Belgium
14:50–15:00	Discussion and closing remarks	All
15:00–15:30	**Coffee break**	

15:30–17:00	**Technical Session 3** **ANIMALS AND ANIMAL FEEDS** Chair: Mr Ivancho Naletoski Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture International Atomic Energy Agency	
15:30–15:50	3.1 Radioactive caesium contamination of grassland	Ms Yasuko Togamura Institute of Livestock and Grassland Science, National Agriculture and Food Research Organization, Japan
15:50–16:10	3.2 The basics caesium-137 of animal production under conditions of radioactive contamination	Mr Viktar Averin Biology Department of Gomel State University, Belarus
16:10–16:30	3.3 The influence of the season on the levels of activities in crops following a short-term deposition of radionuclides to agricultural land	Mr Gerhard Proehl Division of Radiation, Transport and Waste Safety, International Atomic Energy Agency
16:30–16:50	3.4 Radioactivity monitoring and emergency preparedness in meat and animal feeds in Austria	Mr Christian Katzlberger Austrian Agency for Health and Food Safety (AGES), Austria
16:50–17:00	Discussion and closing remarks	
17:30–19:00	Hospitality Event hosted by NARO	

Tuesday, 18 October 2016

Time	Activity	Speakers
09:00–10:30	**Technical Session 4** **FOOD AND COMMODITIES (POST-HARVEST)** Chair: Mr Carl Blackburn Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture International Atomic Energy Agency	
09:00–09:20	4.1 Radioactive caesium dynamics during food processing	Ms Mayumi Hachinohe Food Research Institute, National Agriculture and Food Research Organization, Japan
09:20–09:40	4.2 Food management following the Chernobyl Accident	Mr Mikhail Balonov Research Institute of Radiation Hygiene, Russian Federation
09:40–10:00	4.3 Countermeasures on agricultural areas after the Chernobyl and Fukushima accident	Ms Vanessa Durand Institute for Radiation Protection and Nuclear Safety (IRSN), France
10:00–10:20	4.4 Radiation monitoring of contaminated foodstuffs in Poland after the Chernobyl accident	Mr Dawid Frencel National Atomic energy Agency(PAA), Poland
10:20–10:30	4.5 Remediation Strategies for Radioactive Contamination of Agricultural Environment toward Food Safety in Pakistan	Mr. Ihsanullah Ihsanullah Nuclear Institute for Food & Agriculture (NIFA), Pakistan
10:30–10:35	Discussion and session closing remarks	All
10:35–11:00	**Coffee break**	

11:00–12:00	**Technical Session 5** **SOCIOECONOMIC ASPECTS** Chair: Ms Brenda Howard Centre for Ecology and Hydrology, Lancaster Environment Centre, UK	
11:00–11:20	5.1 Current and past situation of disaster area in Fukushima	Mr Yuzo Mampuku Central region Agricultural Research Center, National Agriculture and Research Organization, Japan
11:20–11:40	5.2 Chernobyl: Socio-economic and environmental impacts and prospects	Mr Martin Krause, Division for Europe, Department of Technical Cooperation, International Atomic Energy Agency
11:40–12:00	5.3 Job structures of farm households and direction to restoring farming in disaster area	Mr Akihisa Nonaka Tohoku Agricultural Research Center, National Agriculture and Food Research Organization, Japan
12:00–12:30	Discussion and closing remarks	All
12:30–13:30	**Lunch break**	
13:30–15:45	**Closing Session** Chair: Mr Takuro Shinano Tohoku Agricultural Research Center, National Agriculture and Food Research Organization, Japan Rapporteurs: Mr Carl Blackburn and Mr Ivancho Naletoski Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture International Atomic Energy Agency	
13:30–14:30	Discussion, conclusions and recommendations	All
14:30–15:00	**Coffee break**	
15:00–15:30	Finalization of conclusions and recommendations	All
15:30–15:45	Closing addresses	Mr Imbe Tokio, President of National Agriculture and Food Research Organization, Japan Mr Qu Liang, Director of Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture International Atomic Energy Agency

Annex

SUPPLEMENTARY FILES

Opening Statements and Sessions

List of Participants

The supplementary files for this publication can be found on the publication's individual web page at www.iaea.org/publications.

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