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Toward the environmental restoration of disaster areas:

Research on the recovery of environments contaminated with radioactive substances

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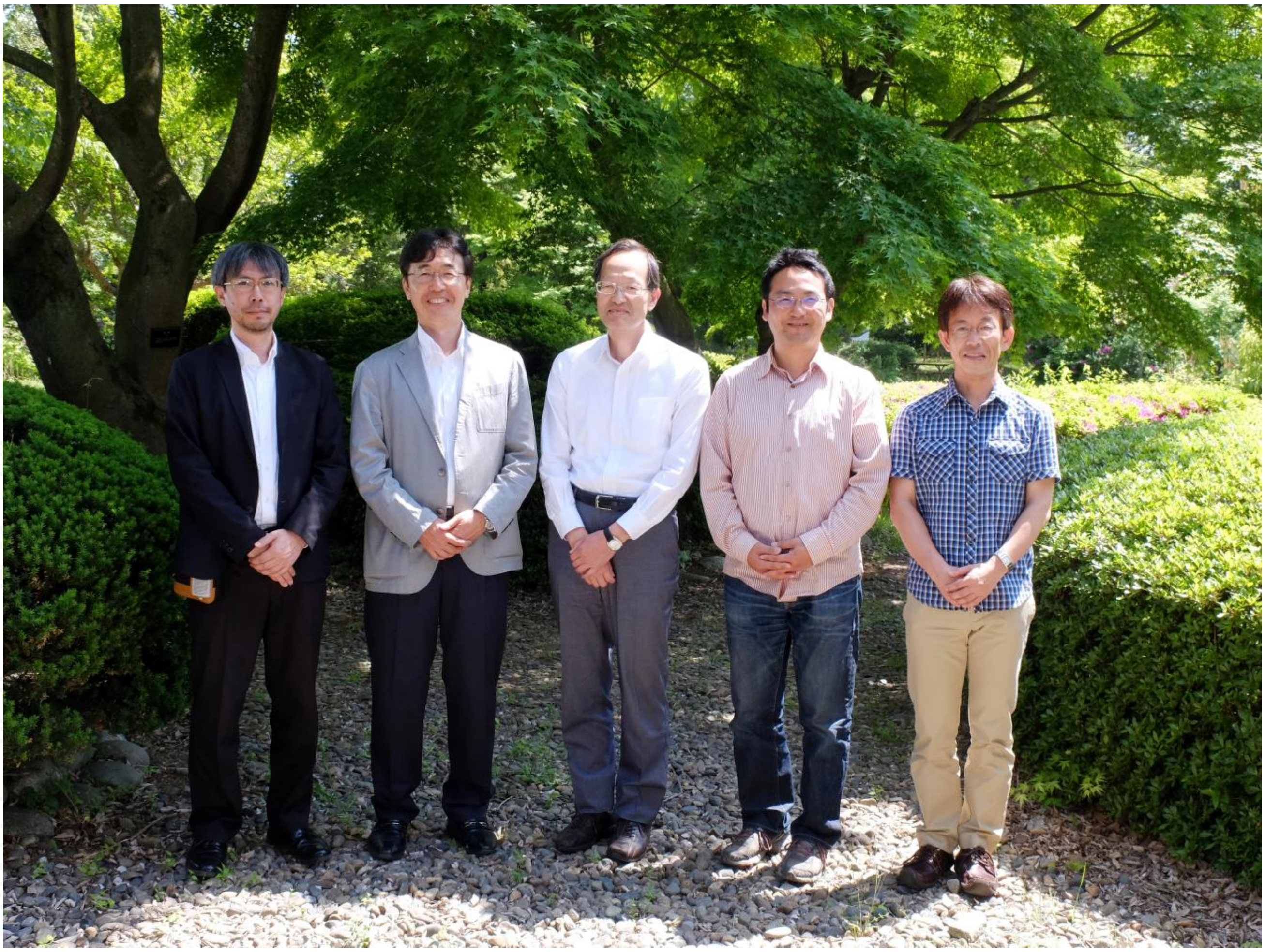
National Institute for Environmental Studies (NIES) researchers from various disciplines have worked together since immediately after the Great East Japan Earthquake (GEJE) to conduct a wide range of research in support of disaster areas.

These initiatives have led to the launch of a new "environmental emergency" research field aimed at disaster area environmental recovery based on knowledge and experience in environmental research that NIES has built up over many years.



Contents

Five and a half years have passed since the GEJE struck on March 11, 2011. Steady progress is being made on environmental recovery and reconstruction in Fukushima Prefecture and other affected areas, but major problems and challenges remain as a result of damage caused by the earthquake and tsunami as well as contamination of the environment with radioactive substances.

Leveraging its rich experience in environmental research from immediately after the GEJE, NIES has conducted research on the treatment and disposal of debris and other disaster waste, including waste contaminated with radioactive substances, the environmental dynamics of radioactive substances and their impact on organisms and ecosystems, environmental changes and impacts caused by earthquakes and tsunamis, disaster area reconstruction and community development, local area environmental creation and other aspects of environmental emergency research. In fiscal 2016, NIES will set up a branch within the Environmental Creation Center to be established in the town of Miharu in Fukushima Prefecture in order to better conduct sustained investigation and research rooted in the disaster area. NIES will also conduct research on environmental creation to prepare for future disasters based on the experience and lessons of the GEJE.

Since the GEJE, NIES has focused in particular on researching the recovery of environments contaminated with radioactive substances, and this issue introduces these efforts and plans for further research in this area.

Researcher Interview-
Environmental Emergency Research: Achievements to Date and Future Plans

Toshimasa Ohara

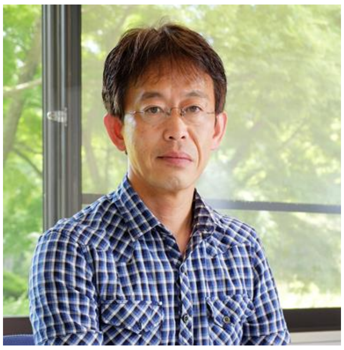
Research Director in Fukushima Branch

Masahiro Osako

Director, Center for Material Cycles and Waste Management Research

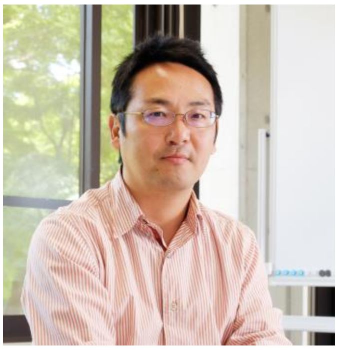
Masato Yamada

Head, Radiological Contaminated off-site waste Management Section in Fukushima Branch



Seiji Hayashi

Research Group Manager in Fukushima Branch



Masanori Tamaoki

Principal researcher of Environmental Impact Assessment Section in Fukushima Branch

Since the GEJE struck, NIES has conducted research related to disasters and the environment (environmental emergency research) aimed at restoring environments contaminated with radioactive substances, and at disaster area reconstruction and regeneration. To better conduct sustained investigation and research rooted in the disaster area, the NIES Fukushima Branch within the Environmental Creation Center was established in 2016 in the town of Miharu in Fukushima Prefecture. Accordingly, we focus in this issue on research for restoring radioactively contaminated environments, asking the following five researchers about efforts to date and plans for the future with respect to the opening of NIES's Fukushima branch: Toshimasa Ohara, who oversees research at the NIES Fukushima Branch, Masahiro Osako of the Development of Management Systems for Radioactively Contaminated Off-Site Wastes project, Masato Yamada of the Radiological Contaminated off-site waste Management project, Seiji Hayashi of the Analysis and Prediction of Radioactive Substances Behavior in Multimedia Environment project, and Masanori Tamaoki of the Research for Impacts on Organisms and Ecosystem project.

This interview was conducted in 2015, before the establishment of Fukushima Branch.

Three programs addressing environmental emergency research

Q: What kinds of research are being carried out?

Ohara: We are conducting environmental emergency research under the three research programs of Environmental Recovery Research Program, Environmental Renovation Research Program, and Environmental Emergency Management Research Program. I myself am responsible for the overall management of NIES's environmental emergency research. The researchers gathered here today are colleagues who lead the Environmental Recovery Research Program.

Osako, Yamada: We are investigating the treatment and disposal of waste contaminated with radioactive substances.

Hayashi: We are investigating the behavior of radioactive substances released and deposited on the land as a result of the Fukushima Daiichi Nuclear Power Plant accident so as to understand their movement and re-accumulation on a river basin scale.

Tamaoki: We are investigating the effects of low-dose radiation and other factors on organisms and ecosystems under our biological and ecological impacts research project. We also conduct research on the processes whereby radioactive substances accumulate in the bodies of organisms.

Conducting investigations in the Special Decontamination Area

Construction of a temporary storage facility for decontamination waste

Q: What are your views on the research carried out so far?

Ohara: I must admit that it's been a tortuous path all along. In addition to our ongoing research, we suddenly had to start focusing on this new area of environmental emergency research, despite having a very limited budget and no organization at first for such research. We have no previous experience in tackling the issue of environmental contamination with radioactive substances, so we were groping in the dark at first.

Column 1.
NIES's Environmental Emergency Research

Our environmental emergency research covers many areas of disaster-related environmental research, including damage to the environment caused by the GEJE, contamination by radioactive substances released into the environment as a result of the earthquake, the impact of those substances on the health of human beings and other life forms, decontamination technologies, and reconstruction efforts to create new environments.

NIES has established three research programs to address these challenges in the field of environmental emergency research. Our Environmental Recovery Research Program is concerned with (1) developing technologies and systems for treating and disposing waste contaminated with radioactive substances (contaminated waste research), and (2) elucidating the behavior of radioactive substances in the environment, and assessing radiation doses and impacts on organisms and ecosystems (multimedia environmental research).

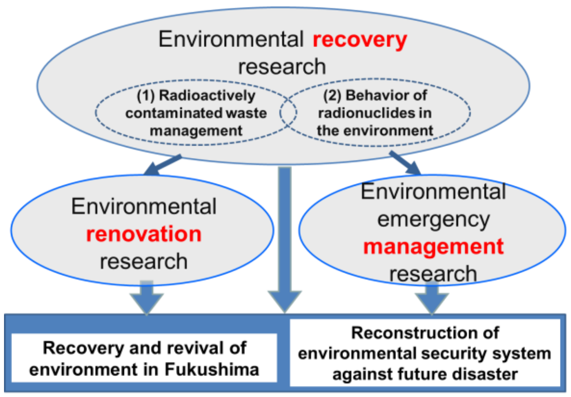


Figure 1. NIES's Environmental Emergency Research

Our Environmental Renovation Research Program is concerned with post-disaster environmental restoration and renovation. Furthermore, our Environmental Emergency Management Research Program is concerned with the building of environmental management systems in preparation for future disasters.

The challenge posed by waste contaminated with radioactivity

Q: How did you find conducting research on radioactively contaminated waste?

Experiment to test the fixation of designated waste (fly ash) in cement

Measuring cesium in the flue gas of an asphalt concrete plant

Osako: At the time, laws governing the treatment of waste had not anticipated waste products containing radioactive substances, but with the nuclear accident, we were suddenly forced to figure out what to do with such waste.

Ohara: We were able to make a big contribution to the country and society as a whole through tackling this issue.

Yamada: We based our research in this area on the waste treatment research that we'd done up to then, so it didn't feel like we were doing something new, but there was so much that needed to be done that we were overwhelmed.

Osako: Since we had little idea of the impacts and risks of radioactive substances, those early days in the lab were fraught with anxiety and tension, but as we became familiar with the science, we realized that we could resolve the issues with existing technology. Once we were convinced of this, the work was very rewarding. The disaster presented us with a huge challenge, but as a result of taking it on, people in the Institute now have the confidence to tackle tough problems, and environmental emergency research has become a major research field.

Q: What kind of research are you carrying out?

Osako: We're carrying out field surveys of locations at which disaster waste and radioactively contaminated waste is being stored or treated, and we're developing technologies for the appropriate treatment of such waste. We're also conducting research on ensuring the safety of waste treatment facilities and on their long-term management.

Column 2.
Radioactive substances, radioactivity, radiation, radiocesium

(1) Radioactive substances, radioactivity, radiation

· Radioactivity: Ability to emit radiation through decay of the nuclei of atoms

· Radioactive substances: Generic term for substances that emit radiation

· Radiation (ionizing radiation): Beams of particles (including photons) emitted through the decay of atomic nuclei. Types of radiation include α-rays, β-rays, and γ-rays.

Amounts of radioactivity are expressed in becquerels (Bq), and radiation dose per person in sieverts (Sv) as a measure of effects on human health.

(2) Radiocesium

Radiocesium (^{134}Cs and ^{137}Cs) was released into the environment as a result of the nuclear accident, and is the radioactive substance giving rise to greatest concern for its impacts on human health. Radioactive substances decay and decrease over time. ^{134}Cs has a half-life (i.e. decreases by half) of about two years, and ^{137}Cs, about 30 years. ^{134}Cs and ^{137}Cs were released in roughly equal quantities from the nuclear power plant, and were present in the environment immediately after the accident in a roughly 1:1 ratio. However, because of the difference in their half-lives, the ratio of ^{137}Cs to ^{134}Cs had become 3.5:1 by March 2015, four years after the accident, and this ratio will continue to increase over time.

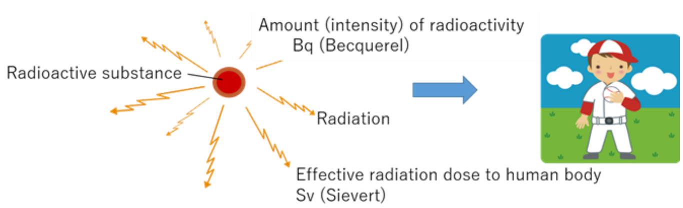


Figure 2. Radioactive substances, radioactivity, radiation, becquerels (Bq) and Sieverts (Sv)

Yamada: The government issued a notice in late June 2011, to the effect that fly ash (very fine ash suspended in flue gases that is generated when waste etc. is incinerated) containing less than 8000 Bq/kg of radiocesium could be landfilled. Later, during the typhoon season, I visited a disposal site.

Osako: Because radiocesium contained in fly ash is easily soluble in water, there was a risk of radioactive substances being leached from landfilled fly ash by rainwater if it was buried as is, so I felt that it was necessary to take measures of some kind. That's why I hastily had Dr. Yamada go to the site. Fortunately, radiocesium concentration in the site's leachate discharge turned out to be very low, so leaching didn't pose any big problem.

Yamada: When I saw the site in heavy rain, I felt strongly that we needed to do something as soon as possible to prevent exposure of the fly ash to rainwater. We provided related scientific information to regulators, and in the end this was incorporated into legal standards.

Osako: This case reminded me of the importance of seeking action when we're convinced of the need to do so.

Q: The tsunamis that followed the GEJE created huge amounts of debris and other waste, didn't they?

A regular check of river water quality in Fukushima Prefecture's Hamadori region

Using a sediment core sampler to collect sediment from a boat on Lake Hayama in the upper reaches of the river Manogawa in Fukushima Prefecture

Osako: Yes, in the first two months after the quake struck, we really were working around the clock to deal with it all. The amount of disaster waste was anyway enormous, and there were nowhere near enough treatment facilities. As such, the government had to both build new facilities and persuade other prefectures to store waste that couldn't be treated immediately. The problem with this is that it's really difficult to obtain the consent of local residents.

The fact that we live in an information society now makes it even more difficult, since all the different information circulating on the Internet tended to impede rather than aid correct understanding of waste treatment. And because people had also lost confidence in government, they were very reluctant to lend an ear at town meetings to explanations that new waste treatment facilities were needed to restore the environment. Now that new facilities have been built that are processing waste safely, and progress is being made on the construction of further new facilities, I think that people are slowly becoming more accepting of such facilities.

Q: What kind of problems remain?

Osako: The disaster served as a rude reminder of the difficulty of finding locations for waste treatment facilities. I think we need to create the mechanisms for enabling society as a whole to take rational decisions not only on the issue of radioactive waste, but also on ordinary waste treatment facilities. From the technical perspective, I think that our research on technologies used in the field has deepened public understanding of normal waste treatment technologies in a big way. I hope to leverage this to implement more positive approaches to new waste treatment.

Yamada: A major issue is what to do with all of the waste contaminated with radioactive substances that's currently in temporary storage. Finding locations for waste treatment facilities has always been a difficult issue. Such facilities have long been regarded as an encumbrance that would tarnish the image of the surrounding

Measuring the radiation dose of morning glory planted for practical use in a junior high school in a "difficult-to-return" zone

Working with flow rate observation apparatus in a forest stream in the upper reaches of the Udagawa in Fukushima Prefecture

district. Deciding on locations took considerable time as a result, and so I don't think we'll be able to resolve all of the outstanding contaminated waste treatment issues anytime soon. We need to think about how we can solve this problem as quickly as possible, and that requires not only technology, but also thinking about ways of achieving consensus between people with opposing viewpoints.

Sense of mission as researchers

Q: What are your views on the environmental impacts research you've carried out so far?

Tamaoki: Immediately after the accident, I felt very keenly that we needed to do something about the radioactive substances released into the environment. Planting sunflowers was one of the most talked-about soil decontamination methods at that time, so we looked into it, but ruled it out on finding that radiocesium doesn't accumulate in the plants. I was also concerned about the biological impacts of radioactivity. Photos showing mutations in animals and plants exposed to radiation in the environment started getting around, and a paper reporting mutations in a butterfly, the Pale Grass Blue (*Pseudozizeeria maha*), also caused a stir. Since any mutations caused by radiation should show in the genes too, we're currently investigating the impact of radiation on wildlife at the genetic level.

Hayashi: Before the accident, we were using a monitoring system on Mount Tsukuba to investigate nitrogen dynamics in forest, and so, out of a sense of mission as NIES researchers, we began to focus seriously on the movements of radioactive substances in river basins.

Ohara: The Mount Tsukuba field survey data has provided the basis for our forest decontamination measures.

Hayashi: Lots of researchers are studying the movements of radioactive substances in forests and rivers, so it's quite a competitive field. It's also an urgent issue for the region's inhabitants, so I feel a heavy responsibility to carry out solid research, and publish our findings as steadily and promptly as possible.

Q: Are you conducting any joint research with other research institutions?

Ohara: We're working with universities, the Japan Atomic Energy Agency and other research institutions to research the behavior of radioactive substances in the environment, and we also hold meetings and such like with related research institutions.

Tamaoki: It's not possible to do the same for research on impacts on ecosystems, since different researchers are studying different organisms. You can't really talk about impacts on ecosystems if you're only studying a certain species. We hope to lead efforts to study the impacts of radioactive substances on ecosystems as a whole by conducting research that encompasses mammals, birds, insects and other classes of organisms.

Ohara: The issue of contamination with radioactive substances touches on a diversity of research fields, which means that cooperation between these fields is necessary. I think we need to marshal resources throughout Japan to conduct this research.

Q: How do you plan to pursue research moving forward?

Tamaoki: The biggest problem we're encountering with research on the impact of radiation on organisms is the paucity of relevant biological data from before the accident. Unfortunately, data from Fukushima Prefecture is particularly scarce, making it impossible to compare status before and after the accident and draw any conclusions about the impacts of radiation. We're accordingly drawing up plans such as, for example, selecting indicator plant and animal species for each prefecture and stocking specimens so as to enable the study of impacts on genes over time in preparation for similar eventualities.

Hayashi: I'm concerned that in the future, even when sufficient progress has been made on the remediation of contaminated locations that are deemed to be safe enough for inhabitants to return, people will nevertheless feel very uneasy about returning. Safety and feeling safe are two different things, and there are many people who won't be convinced even if told that it's safe for them to return. To guarantee peace of mind, we first need to create mechanisms for assessing the risks of returning to live in decontaminated locations.

Despite the large volume of research carried out so far on the movements of radioactive substances in the environment, there are still things we don't know, particularly about movements immediately after the accident.

Column 3.
The problem of radioactively contaminated waste

Radioactive substances released as a result of the nuclear accident were deposited over large swathes of eastern Japan. In these areas, municipal waste containing radiocesium was incinerated in waste incineration plants, resulting in incinerator ash with a high concentration of radioactivity. Also, runoff from soil on which radiocesium had been deposited flowed into waterworks, resulting in rising radioactivity concentrations in sludge forming during sewage treatment and water purification processes. In rural areas, rice straw or compost containing radiocesium has been found, and decontamination efforts have generated huge amounts of decontamination soil and other waste.

Large amounts of different kinds of contaminated waste have consequently piled up in many parts of eastern Japan, and are expected to continue to accumulate. These wastes need to undergo a number of different processes after generation, including sorting/storage, collection and transport, intermediate treatment (volume reduction, concentration and separation by incineration, crushing and washing etc.), recycling, and final disposal. Each of these processes poses a range of unprecedented issues. Any delay in the treatment of these wastes will have significant adverse impacts on decontamination efforts, reconstruction, everyday life and industry.

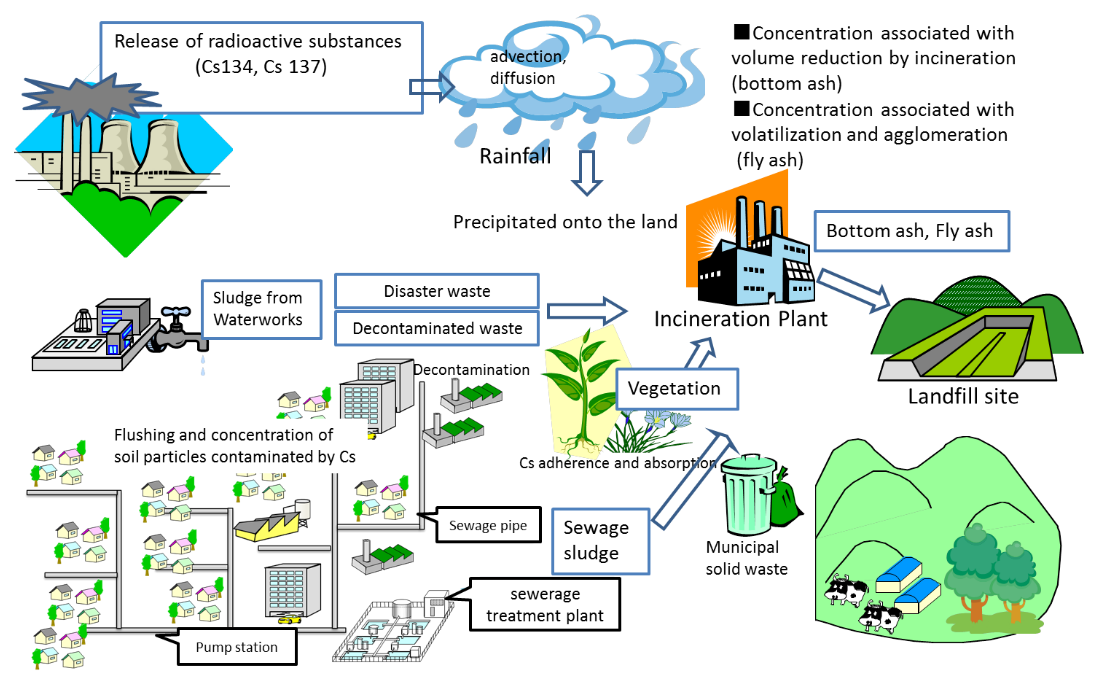


Figure 3. Radiocesium movements in various radioactively contaminated waste and in treatment and disposal processes

We need to organize available research findings in a way that enables us to draw lessons from the Fukushima accident and help to keep the spread, duration, and volume of radioactive waste to an absolute minimum in the event that a similar accident occurs in the future.

Earning trust

Q: What kind of research do you hope to carry out at the NIES Fukushima Branch?

Ohara: The NIES Fukushima Branch will be housed in the Environmental Creation Center to be opened in the town of Miharu in Fukushima Prefecture in 2016 (see Column 7). We're currently making necessary preparations, and plan to conduct environmental emergency research under the following three research programs: Environmental Recovery Research Program, Environmental Renovation Research Program, and Environmental Emergency Management Research Program (see Column 1).

Tamaoki: Once we've moved to Fukushima Prefecture, we may well become aware of circumstances that remain unknown to us in Tsukuba where NIES is based, and our research approach might change as a result. I hope to do my best to respond to the wishes of local inhabitants as I study the impacts of radiation on organisms and ecosystems.

Column 4.
Research on the treatment and disposal of radioactively contaminated waste

The widespread generation of many different kinds of radioactively contaminated wastes was an issue that no one had ever faced before, and relevant scientific knowledge was in short supply at first. Addressing this kind of issue requires knowledge about the radioactive substances that are the source of contamination (mainly radiocesium in this case). However, even more important than this is knowledge and experience of all kinds in the area of waste treatment and disposal. Because much of the huge amounts of disaster waste generated by the GEJE and accompanying tsunamis was contaminated with radioactivity, we need to develop an accurate picture of the characteristics of disaster waste. Also, these wastes were in a wide variety of environments according to location; so, any management of those wastes requires a field-based approach.

NIES has long experience in research that puts priority on fieldwork in finding solutions to difficult waste issues such as dioxins and final waste disposal. We are now making the most of this experience and knowledge, together with our network of experts and all other resources at our disposal, to tackle the issue of radioactively contaminated wastes.

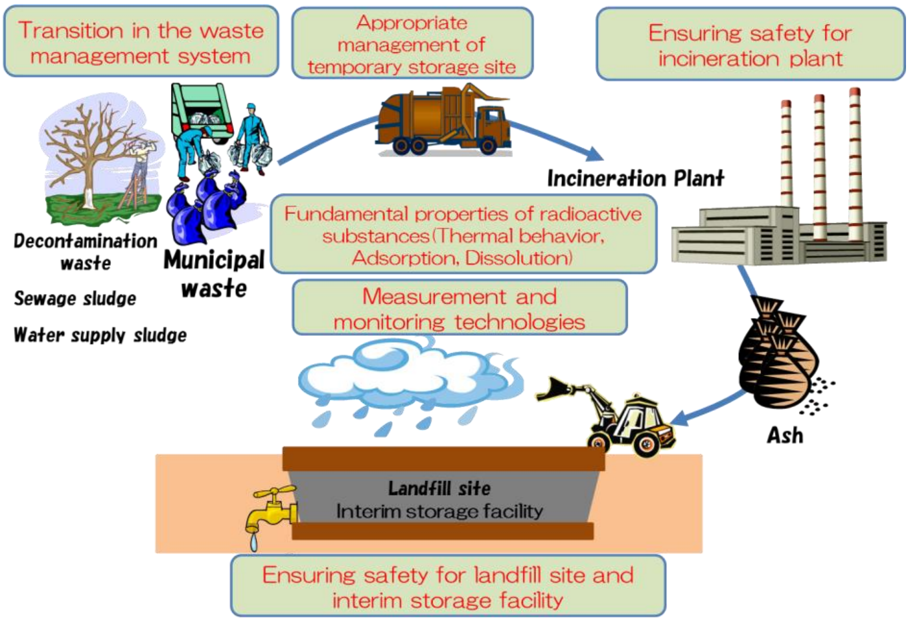


Figure 4. Research on the treatment and disposal of radioactively contaminated wastes. NIES is conducting research on the safe management of processes for treating radioactively contaminated soil and other wastes. (Note: "Thermal behavior" refers to the physico-chemical changes that radiocesium undergoes during the heat treatment process.)

Hayashi: I will of course be carrying out scientific research, but I hope also to become the kind of researcher who can speak candidly with local inhabitants and earn their trust. No matter how much information we communicate, we won't be able to get people to listen to us unless they trust us. I hope to leverage the network I've built up so far, and expand it further. To that end, I want to further strengthen teamwork within NIES to enable us to carry out our research with a shared sense of purpose.

Yamada: What we need to do first is research on interim storage facilities for temporarily stored soil and waste generated by decontamination operations. Safety management of interim storage facilities is an important aspect of such research. I also want to do whatever I can to tell the world about this experience, and to make the NIES Fukushima Branch the world's leading facility for disaster waste management and disaster response.

Osako: Now that we've broken the back of the emergency work of dealing with the disaster and accident, we're left with challenges that will take a long time to address. As Dr. Yamada said, we can best fulfill our role by telling the world about our experiences and what we've learned. We also want to become a research facility that the local people trust.

Ohara: We want to become a research facility that the people of Fukushima Prefecture trust. In Fukushima, our keywords will be livelihoods and living environment. We can understand the living environment only by actually living there ourselves. We want to put down roots in the locality and conduct research that will eventually guarantee the future livelihoods of the local inhabitants. To that end, we want to do our best to connect the Environmental Recovery Research Program that we spoke about today to our Environmental Renovation Research Program. I also hope to make the NIES Fukushima Branch an organization whose researchers can grow as environmental researchers and work at the forefront of environmental issues.

Column 5.
Movements of radioactive substances in the environment

The nuclear accident released a large amount of radioactive substances into the environment. Radioactive substances released into the atmosphere were transported and dispersed widely by wind, eventually being deposited on forests, agricultural land and built environments not only in Fukushima, but also in neighboring prefectures, southern Kanto and other regions, and finding their way into river water, soil, agricultural, forestry and fisheries products, sewage and water treatment sludge, waste incinerator ash (see Column 3) and various other environmental media. These radioactive substances decay and decrease in quantity over time (see Column 2), but those remaining in the natural environment move little by little within the same medium and migrate from one medium to another.

Developing an accurate picture of the movement of radioactive substances in natural environments and predicting future movements is vital to environmental restoration in areas contaminated with radioactive substances.

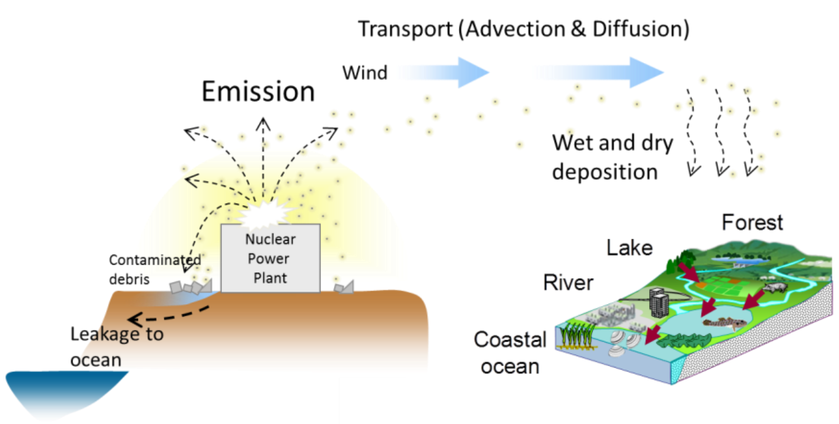


Figure 5. Schematic diagram of movements within the natural environment of radioactive substances released from a nuclear power plant.

Column 6.
Research on the movements and impacts of radioactive substances in the environment

NIES is researching various aspects of the movements and impacts of radioactive substances in the environment. One such research project is focused on utilizing environmental measurement and wide-area environmental simulations to ascertain the extent of contamination and environmental dynamics of radioactively contaminated soil, forests, rivers, lakes, coastal waters etc. at the watershed level, and predict future trends. We are also conducting research to develop a method for the regional estimation of human radiation doses and use it to ascertain exposure levels. While researching the impacts of radioactive substances on organisms and ecosystems, we have also embarked on research on changes in ecosystems resulting from human evacuation and decontamination, and on ecosystem management. The outcomes of this research are being used to support the environmental recovery measures being implemented by national and local governments.

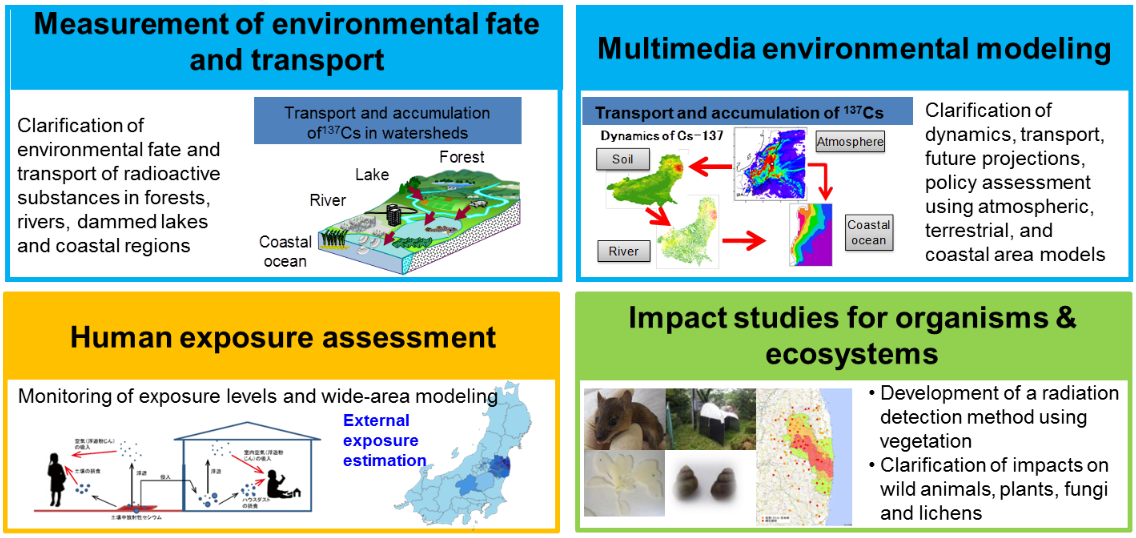


Figure 6. Research on the movements and impacts of radioactive substances in the environment.
NIES is researching the use of environmental measurement and simulation to ascertain the movements of radioactive substances in the environment, and is also studying human exposure to radiation and impacts on organisms and ecosystems.

Summary-

Research on environmental recovery from contamination with radioactive substances

There are many aspects of disaster area recovery-related environmental research that require our urgent attention, including environmental contamination by radioactive substances released into the environment as a result of the nuclear power plant accident caused by the GEJE, the impact of those substances on the health of human beings and other life forms, and technologies for the treatment and disposal of contaminated waste. NIES has been involved in this research since immediately after the disaster occurred.

Development of technologies and systems for waste treatment and disposal

The Tokyo Electric Power Fukushima Daiichi Nuclear Power Plant accident occurred closer to densely populated areas than the 1986 Chernobyl accident. As a result, the waste generated in conjunction with our everyday life also became contaminated with radioactive substances, and these were subsequently concentrated in incinerator ash when the waste was incinerated. This prevented the disposal of some of the ash, which is still in temporary storage as a result. Decontamination of contaminated locations also generated huge amounts of decontamination waste and soil that still await proper treatment.

We have been energetically researching and developing technologies for the appropriate treatment of contaminated waste and other materials. We first needed to check that radioactively contaminated wastes were being safely processed in incineration facilities. Bag filters and other advanced treatment systems are used to treat flue gas as a dioxin countermeasure, and we were able to confirm from a survey of multiple facilities that the same technologies are also extremely effective with respect to radiocesium. We also focused intensely on elucidating the mechanisms guaranteeing this effectiveness. Using chemical equilibrium theory, we have developed a method for estimating the chemical form and properties of radiocesium within an incinerator (Figure 7), and we continue to study ways of boosting the accuracy of estimates while also conducting experimental observations etc.

The ash generated in incineration facilities consist of two types, namely bottom ash that collects in the bottom of incinerators, and fly ash composed of metals etc. volatilized in flue gas and subsequently cooled and condensed as dust. Our research clarified the chemical form of radiocesium in bottom ash and fly ash, enabling estimation of its solubility in water. The radiocesium found in fly ash trapped in filters was found to take the form of cesium chloride, which is very easily soluble in water. This means that if contaminated fly ash is landfilled, it needs to be very strictly managed so as to ensure that it does not contaminate the surrounding water environment. We examined various methods for ensuring that such fly ash does not come in contact with rain, including covering the ash with an isolation layer, or solidifying it in cement. Radiocesium is also known to adsorb very strongly to clay minerals found in soil; we were concerned that leachate containing high salt concentrations that results when fly ash is landfilled would reduce this adsorption capacity. We accordingly measured the adsorption capacity of soil under various salt concentrations, and submitted our recommendations for the appropriate thickness of a soil adsorption layer.

We have also researched and provided our findings on various other technologies, including measurement and monitoring technologies and disposal technologies that make use of concrete. Our findings have been reflected in guidelines and the technical standards of national laws, and constitute the scientific basis on which industry develops technologies.

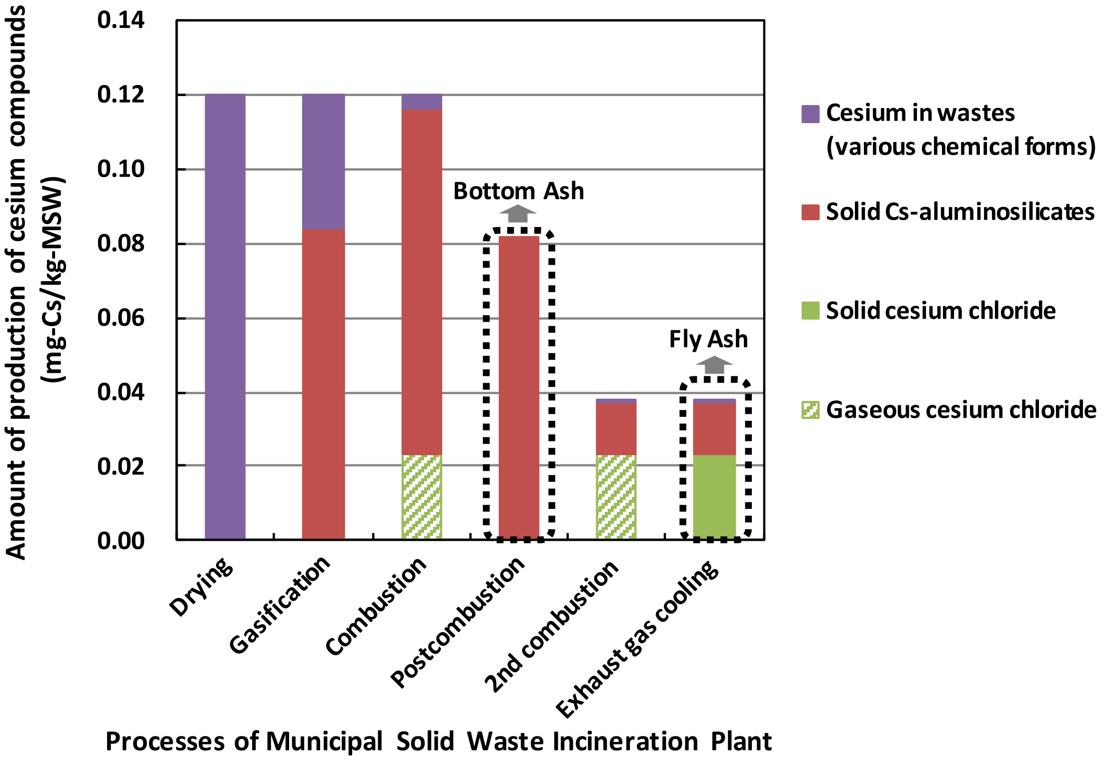


Figure 7. Cesium compounds and their quantities in each zone as calculated using multi-zone equilibrium calculation. We developed an incineration simulator that uses multi-zone equilibrium calculation to calculate the quantities of radiocesium compounds produced in an incineration facility. Multi-zone equilibrium calculation is a method whereby an incineration facility is divided into different zones according to function (drying, thermal decomposition, combustion, etc.), and equilibrium calculations are conducted for each zone. We have confirmed the validity of values obtained by this method for the concentrations of major flue gas components. We also found our simulator to be able to relatively well reproduce rates of migration of radiocesium to different ash types. The graph shows the chemical form of cesium compounds and quantities produced in an incineration facility. The simulation results suggest that most of the radiocesium found in fly ash takes the form of cesium chloride. Ascertaining the chemical form in this way enables prediction of ash properties (e.g. radiocesium leachability), thereby making it possible to control those properties to a certain extent through adjusting incineration conditions.

Ascertaining environmental dynamics and impacts on organisms and ecosystems

We have used environmental dynamics measurement and environmental monitoring to ascertain and predict future trends in the status of contamination and environmental dynamics for forests, rivers, lakes and coasts contaminated with radioactive substances, and have also conducted research on the impacts of radioactive substances on organisms and ecosystems.

Most of the land contaminated by radiocesium from the Fukushima Daiichi Nuclear Power Station accident is forest. To ascertain the dynamics of radiocesium in these forests for the purpose of considering decontamination methods, we used two sites—Mount Tsukuba in Ibaraki Prefecture and the upper reaches of the river Udagawa in northeast Fukushima Prefecture. Given its long half-life of about 30 years, we focused on ^{137}Cs, investigating the way it is deposited on trees, is carried into the soil and drains into rivers.

We started our investigations on Mount Tsukuba immediately after the accident; we found that ^{137}Cs was deposited on the leaves and branches of trees at the time of the accident, transferred to the soil as a result of being washed off by rain and leaf fall, and present in greater quantities in the soil one year after the accident than immediately after the accident. Our investigation of changes over the years in depth of ^{137}Cs found in soil showed that even after three years since the accident, over 90% of ^{137}Cs originating from the accident at both sites was found to be limited to the top 5 cm of the soil. Particularly in the upper reaches of the Udagawa river basin, we found that a considerable amount of ^{137}Cs still remains in the leaf litter layer (Figure 8). We also found that amount of ^{137}Cs flowing from forest zones into rivers each year is only a tiny fraction of the total amount deposited on the watersheds, estimating this to be less than 0.3% per year for both the Mount Tsukuba and Udagawa sites.

There was concern in Fukushima Prefecture over the impacts of radiation derived from the Fukushima Daiichi Nuclear Power Plant accident on wildlife. Radiation is known to damage DNA and induce mutations. Organisms have the power to quickly repair such DNA damage, but if this balance is disturbed, damage to DNA accumulates, and even though the probability is low, mutations can occur as a result.

To assess whether the DNA damage caused by radiation from the soil in Fukushima Prefecture exceeds the repair capacity of organisms, we used a genetically modified *Arabidopsis thaliana* variety that enables visual quantification of DNA damage repairs, cultivating it using soil collected from Fukushima Prefecture. We looked at the relationship between the cumulative radiation dose received by the plants during the 30-day cultivation period and amount of DNA repair, and found that repairs rose with radiation dose, and mutations were not building up.

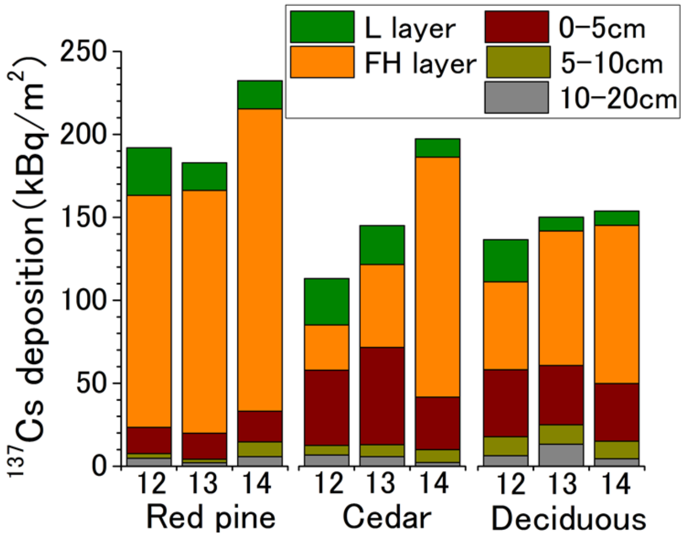


Figure 8. Changes over three years in depth profile of ^{137}Cs in the soil of forest in the upper reaches of the river Udagawa in Fukushima Prefecture. To ascertain the vertical migration of ^{137}Cs deposited on forest soil, we investigated changes in the depth profile of ^{137}Cs in soil of two forested sites—Mount Tsukuba in Ibaraki Prefecture and the upper reaches of Udagawa River in Fukushima Prefecture—over a period of three years. We found that ^{137}Cs deposited on the leaves and branches of trees in the evergreen coniferous forest of Ibaraki Prefecture's Mount Tsukuba at the time of the accident was present in greater quantities in the soil one year after the accident than immediately after the accident as a result of leaf fall and foliar washoff by rain. Particularly in the upper reaches of the Udagawa river basin, we found that a considerable amount of ^{137}Cs still remains in the leaf litter layer (L and FH layers in the graph) composed of fallen leaves and branches. Since it has also been reported elsewhere that a large part of the ^{137}Cs originally found in leaf litter later migrated to the lower mineral soil layer, the speed of downward migration of ^{137}Cs would appear to differ according to location. This suggests that decontamination by removal of the litter layer should be conducted only after considering the ^{137}Cs depth profile of the location concerned.

Resolving the problems of areas affected by the GEJE

We face a mountain of problems regarding restoration of the environment in GEJE disaster areas in Fukushima Prefecture and elsewhere. We are accordingly working with other research bodies both in Japan and overseas to (1) ascertain the status of environmental contamination with radioactive substances and the movement and accumulation of these substances, identify long-term trends, and predict the effectiveness of decontamination and other countermeasures through long-term monitoring and modeling; (2) evaluate and predict changes to ecosystems disturbed by evacuation of the human population and decontamination operations, and assess the impacts of radiation etc. on wildlife; (3) develop safe and effective technologies and systems for treating and disposing of waste and soil contaminated with radioactive substances.

On our research-

The current status of environmental restoration research and NIES's environmental emergency research

Restoring environments contaminated with radioactive substances is a matter of great urgency for areas affected by the GEJE. As a core organization conducting comprehensive environmental research, NIES has worked with a great many other public and private sector organizations and academia to carry out multifaceted research that will help to restore the environment of affected areas. In addition to continuing with our Environmental Recovery Research Program, we will integrate this program with environmental emergency research aimed at renovating post-disaster regional environments and equipping them to withstand future disasters.

In Japan

Many different research institutions, government agencies, and researchers are conducting research on radioactive substances released into the environment as a result of the Fukushima Daiichi Nuclear Power Plant accident. This research includes methods for measuring radioactive substances; the dynamics and impacts of these substances in the environment; decontamination, treatment and disposal of waste; and many other areas; the researchers carrying out this work are specialists in many different academic fields. Developing an accurate overall understanding of all this research is not easy, but the recommendation published by the Science Council of Japan on September 19, 2014, titled "Long-term Radioactivity Countermeasures for Reconstruction: The Need for Cross-Agency Radioactivity Countermeasures with Active Participation of Academic Experts "[1], serves as a useful panoramic overview. It includes a chart titled "Movements of radioactive materials between media, and main research bodies" that lists the Ministry of the Environment; Ministry of Education, Culture, Sports, Science and Technology; the Nuclear Regulatory Agency; Fukushima Prefecture; research organizations (NIES, the Japan Atomic Energy Agency, and others)[2]; universities (University of Tsukuba, University of Tokyo, Tokyo University of Marine Science and Technology, Ibaraki University, Tokyo Institute of Technology, and others); and the Tokyo Electric Power Company. Large-scale interdisciplinary research projects are also underway, such as the Ministry of Education, Culture, Sports, Science and Technology (MEXT) Grant-in-Aid for Scientific Research on Innovative Areas' "Interdisciplinary Study on Environmental Transfer of Radionuclides from the Fukushima Daiichi Nuclear Power Plant Accident" project.

At NIES

Leveraging its rich experience in environmental research, NIES has, since immediately after the GEJE struck on March 11, 2011, investigated environmental issues caused by the earthquake, tsunami, and the Fukushima Daiichi Nuclear Power Plant accident, positioning this research as Environmental Emergency Research (NIES Research Booklet No.49).

We shifted these research activities into high gear in the second half of fiscal 2011, focusing in particular on developing technologies and systems for the proper treatment and disposal of disaster waste and waste contaminated with radioactive substances (contaminated waste research), and on elucidating and predicting the behavior of radioactive substances in the environment through measurement and simulation, and assessing human radiation doses and impacts on organisms and ecosystems (multimedia environmental research). We have consolidated these two areas of research into our Environmental Recovery Research Program, which is aimed at restoring disaster areas contaminated with radioactive substances as rapidly as possible.

For contaminated waste research (on waste materials and soil contaminated with radioactive substances), we are conducting field surveys, basic experiments, field verification tests, systems analysis and other research on the development, refinement and evaluation of disposal process control technologies and systems (temporary storage, volume reduction through incineration, reuse, interim storage, final disposal, etc.), and on methodologies for the long-term management and eventual dismantling and removal of related treatment facilities based on the fundamental physical properties and behavior of radioactive substances. We are also studying measurement, analysis and monitoring technologies, radioactive substance management strategies, and stock and flow in waste disposal/resource recycling systems, and risk communication methods. We are contributing to the appropriate treatment and disposal of contaminated waste by collating and providing our research findings to the Ministry of the Environment and other bodies.

For multimedia environment research, we are conducting research that combines multimedia environmental monitoring, environmental dynamics measurement and environmental data analysis to ascertain and predict future trends in the status of contamination and environmental dynamics for soil, forests, rivers, lakes and coasts of watersheds suffering various degrees of contamination with radioactive substances. Our research findings in this area are providing scientific support for the environmental recovery measures being implemented by national and local governments. We have developed a method for the wide-area estimation of human radiation doses and are using it to ascertain exposure levels. We are also researching the impacts of radioactive substances on organisms and ecosystems, and have embarked on research on changes in ecosystems resulting from human evacuation and decontamination.

In addition to this Environmental Recovery Research Program, we are implementing two other research programs—our Environmental Renovation Research Program for supporting disaster area reconstruction and sustainable community development, and our Environmental Emergency Management Research Program for leveraging the experience and lessons of the GEJE to prepare for future disasters from the environmental perspective (Column 1).

NIES is committed to supporting the reconstruction and environmental recovery of GEJE disaster areas through research and technology within the framework of these three Environmental Emergency Research programs, and to contributing to the creation of sustainable technological and social systems equipped to withstand future disasters. To this end, we are further intensifying our research activities by opening the NIES Fukushima Branch in 2016 as a new local NIES research base within the Environmental Creation Center currently under construction in the town of Miharu in Fukushima Prefecture.

-Annotation-

1. http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-22-t140919.pdf (in Japanese)
2. Japan Atomic Energy Agency, National Institute for Environmental Studies, Meteorological Research Institute, Central Research Institute of Electric Power Industry, National Institute of Radiological Sciences, Japan Agency for Marine-Earth Science and Technology, National Agriculture and Food Research Organization, National Institute for Agro-Environmental Sciences, Forestry and Forest Products Research Institute, Fisheries Research Agency, National Institute of Public Health, National Institute of Health Sciences

Column 7.
NIES Fukushima Branch and the Environmental Creation Center in Fukushima Prefecture

The Environmental Creation Center is a facility built by Fukushima Prefecture to hasten the recovery of radioactively contaminated environments and create an environment in which people can live with peace of mind into the future. The Minamisoma-shi facility was completed in September 2015, and Miharu-machi facility in March 2016. NIES and the Japan Atomic Energy Agency (JAEA) occupy the research block of the Miharu-machi facility, working together with Fukushima Prefecture on environmental recovery and renovation research.

In April 2015, we signed a “Basic Agreement on Cooperation within the Environmental Creation Center” with Fukushima Prefecture and JAEA. We opened the NIES Fukushima Branch in June 2016, occupying approximately half of the research block (yellow dotted oval). Here we are going to conduct environmental emergency research in cooperation with Fukushima Prefecture, JAEA and many other associated public and private sector organizations and academic institutions.

Figure 9. The Environmental Creation Center being built in Miharu-machi, Fukushima Prefecture (artist’s rendering of completed facility)