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Outline of Environmental Emergency Research in NIES

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National Institute for Environmental Studies, Japan

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Foreword

The National Institute for Environmental Studies (NIES), Japan is a leading institute implementing comprehensive environmental research across a wide range of fields. We began environmental research activities to respond to and recover from the earthquake, tsunami and subsequent accident at the Fukushima Daiichi Nuclear Power Plant in the immediate aftermath of the Great East Japan Earthquake (GEJE) of March 11, 2011. These activities are currently being furthered under the umbrella of ongoing research initiatives on “Environmental Emergency Research”. Environmental Emergency Research at NIES is conducted under the following research programs: (1) Environmental Recovery Research Program, (2) Environmental Renovation Research Program, and (3) Environmental Emergency Management Research Program. Our existing and consequently obtained scientific expertise and outcomes have been reflected in policymaking for recovery from the GEJE, as well as environmental creation in its aftermath. Furthermore, plans for a NIES Fukushima branch, which will serve as a base for our further activities in Environmental Emergency Research, to be established in the Centre for Environmental Creation in Fukushima prefecture, and intended to be operational in spring 2016, are currently at an advanced stage.

In this context, we have undertaken this initiative to publish a series of booklets on Environmental Emergency Research, with the aim of sharing the know-how and scientific findings we have acquired in the course of our activities in this area to date, as well as outcomes of inter-disciplinary research conducted in collaboration with international bodies and institutions and the scientific community as a whole. This booklet entitled “Outline of Environmental Emergency Research at NIES” is the first volume in a planned series of booklets and is based on reference materials prepared for the “1st NIES International Advisory Board” successfully convened in August of this year. This volume summarizes the major activities and research outcomes for solution to the environmental issues associated with disasters, conducted at NIES over the period from FY 2013 to the present (mid-FY 2015).

We hope that this booklet will facilitate an understanding of Environmental Emergency Research at NIES, and we invite your full and frank feedback and opinions about those activities.

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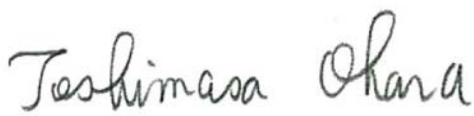
December 2015



Overview of Environmental Emergency Research

1. Overview of research outcomes from FY 2013 to the present (mid-FY 2015)

1.1 Background and aim

There are many areas of disaster-related environmental research related to the Great East Japan Earthquake (GEJE) that require our urgent attention, including damage to the environment, contamination by radioactive substances released into the environment from the Fukushima Daiichi Nuclear Power Station (FDNPS), the impact of those substances on the health of human beings and other life forms, decontamination technologies, and reconstruction efforts to create new regional environments. We will accordingly seek both to contribute to reconstruction and environmental creation in areas affected by the GEJE through conducting integrated research in the four fields detailed below (see Fig.1), and to apply research outcomes to the formulation of environmental policy and measures for remediation of damage suffered by people and the environment as a result of earthquakes and other calamities in general. We will work with Fukushima Prefecture and other local governments in affected areas as well as with other research organizations to carry out this research.

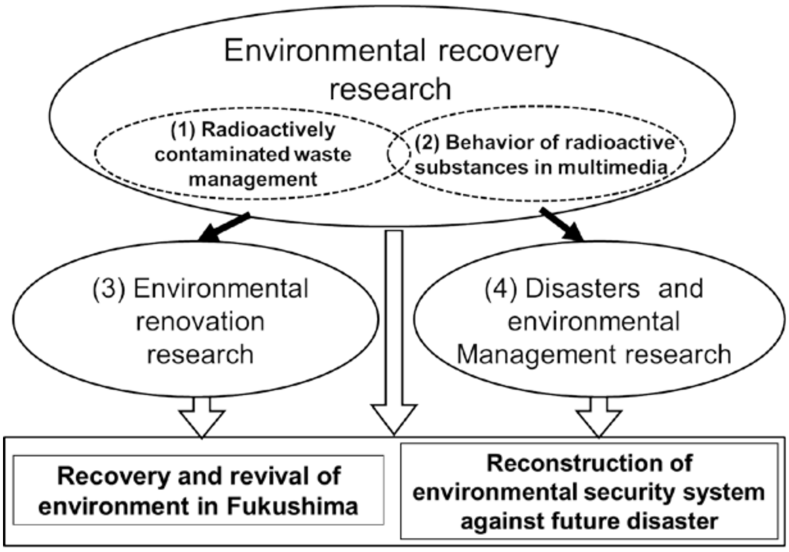


Fig. 1 Overall structure of Environmental Emergency Research

(1) Environmental Recovery Research 1 "Establishment of technologies and systems for managing radioactively contaminated wastes"

With respect to waste materials and soil contaminated with radioactive substances, we will conduct field surveys, basic experiments, field tests, systems analysis and other research on the development, refinement and evaluation of disposal process control technologies and systems (storage, reduction, reuse, 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 will also conduct research on measurement, analysis and monitoring technologies, radioactive substance management strategies and system-wide flow/stock in waste disposal/resource recycling systems, and risk communication methods. We will contribute to the appropriate treatment and disposal of contaminated waste by collating and disseminating our research findings.

(2) Environmental Recovery Research 2 "Study of the dynamics of radioactive materials in multimedia environments"

We will conduct 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 undergoing various degrees of contamination with radioactive substances. We will also develop a method for the wide-area estimation of human radiation exposure and use it to ascertain actual exposure levels. While researching the impacts of radioactive substances on organisms and ecosystems, we will embark on research on changes in ecosystems resulting from human evacuation and decontamination, and on ecosystem management. Through these activities, we will endeavor to provide scientific outcomes that support ongoing and forthcoming environmental recovery measures being implemented by the national and local governments.

(3) Environmental Renovation Research "Promotion of surveys and research towards restoration and environmental creation for the post-disaster regional environment"

We will work with the Fukushima Prefecture municipalities of Shinchi and Minamisoma, where reconstruction is underway, to develop research theory and methods for supporting the process of restoration and environmental creation in post-disaster regional environments, and conduct research on supporting the policymaking of local governments using those methods. We will also consider such aspects as global warming countermeasures and resource recycling strategies tailored to the characteristics of affected areas, and conduct practical research aimed at building regional environmental resource and energy systems and formulating quantitative eco-city policy targets and roadmaps for achieving those targets.

(4) Environmental Emergency Management Research "Studies on establishment of the environmental management system prepared for future disasters"

To prepare for earthquakes and other anticipated disasters, we will systematize and generalize the outcomes of research on the GEJE and other disaster-related environmental research, and conduct research to support environmental impact assessment and the creation of a disaster-resilient society, including more robust resource recycling and waste management for disaster debris and the establishment of environmental and health risk management strategies.

1.2 Research and other outcomes

We have worked with the Ministry of the Environment, with Fukushima Prefecture and other regional governments in affected areas, and with other research institutes to conduct urgent, wide-ranging, integrated disaster-related environmental research on the damage to the environment caused by the GEJE; contamination by radioactive substances released into the environment; the impact of those substances on organisms and ecosystems; decontamination technologies and technologies for treating contaminated waste; and reconstruction efforts to create new regional environments. The resulting research outcomes have made a major contribution to reconstruction efforts and environmental creation in areas affected by the GEJE.

We have also embarked on disaster environmental management research to contribute to the formulation of environmental policy for environmental decontamination and recovery from damage caused to people and the environment by large-scale disasters, outcomes of which have already contributed to tangible results in disaster-related waste disposal and other areas.

We are now preparing to establish an environmental emergency research framework centered on our planned Fukushima branch to be located in the Centre for Environmental Creation, currently being advanced by Fukushima Prefecture.

As a result of the above efforts, we have achieved the outcomes as below.

(1) Environmental Recovery Research 1 "Establishment of technologies and systems for managing radioactively contaminated wastes"

We conducted multifaceted research to tackle the issue of safe and appropriate treatment and disposal of disaster waste contaminated with radioactive substances, and made significant contributions in this area, serving also as a hub for coordinating academic and industry efforts with the core support of the Ministry of the Environment.

- Development and evaluation of waste treatment control technology systems
- Development, refinement and evaluation of treatment, disposal and recycling technologies
- Establishment of technologies for the long-term management of treatment facilities
- Construction of flow/stock model and establishment of measurement monitoring technologies

(2) Environmental Recovery Research 2 "Study of the dynamics of radioactive materials in multimedia environments"

We conducted research in areas such as the quantitative evaluation of radioactive cesium (Cs) flow and stock in watersheds; development of a multimedia environment model; impacts on organisms and ecosystems, and radiation exposure evaluation, contributing to decontamination operations and other disaster zone environmental restoration processes by providing our research findings to the Ministry of the Environment, Fukushima Prefecture and other parties.

- Environmental dynamics measurement
- Multimedia environmental modeling
- Impacts on organisms and ecosystems
- Evaluation of human exposure to radiation

(3) Environmental Renovation Research "Promotion of surveys and research towards restoration and environmental creation for the post-disaster regional environment"

We worked with the local administrations, residents, businesses and other parties in the town of Shinchi in Fukushima Prefecture to conduct research aimed at helping with reconstruction and community development, including expansion of local community information systems and data analysis, development of models for supporting reconstruction plans; development and application of a model for evaluating policies aimed at balancing reconstruction with environmental considerations; and the holding of workshops.

- Development of local information systems for regional environmental creation
- Development of models for analyzing regional environmental creation scenarios
- Development and implementation of participatory environmental creation methods

(4) Environmental Emergency Management Research "Studies on establishment of the environmental management system prepared for future disasters"

We embarked on research to bolster environmental disaster readiness and create support systems after systematically reorganizing our research structure. Research outcomes have been used by the Ministry of the Environment to prepare for the management of disaster waste arising from major earthquakes. We also conducted research on technologies for utilizing disaster waste as reconstruction materials.

- Establishing strategies for bolstering disaster waste management and resource recycling
- Research on strategies for managing environmental and health risks associated with disasters
- Construction of a disaster environment research network hub

1.2.1 Environmental Recovery Research 1 "Establishment of technologies and systems for managing radioactively contaminated wastes"

<u>(1) Research and Development of control technologies for waste management processes</u>

(See chapters 2 [1] and 3 for more details)

To provide a scientific basis for the appropriate disposal of radioactively contaminated off-site waste, thermodynamics, leaching and adsorption-desorption properties and behaviors of the radioactive contaminants in the treatment and the disposal processes were investigated.

Thermodynamics and other physical properties of radioactive substances were obtained. The vapor pressure of radioactive substances was measured. An equilibrium computation was applied to analyze the behaviors of radioactive substances and the effects of coexisting substances on them during the process of incinerating municipal solid waste. Calculated results of this incineration simulator were validated. The behaviors of radioactive substances contained within the biomass and the bottom ash during the process of incineration were identified. These results provided several possible options for appropriate solid waste incineration that can be applied by the Ministry of the Environment and by municipalities. They have been published in various journals as original articles and reviews.

To demonstrate the leachability of radiocesium during the humification of soil and vegetation, share of radiocesium in its water-soluble and ion-exchangeable state were estimated by performing serial-batch and serial-extraction tests. An index of higher leachability was proposed as the rate of distribution of each fraction. For vegetation, the amount of leaching was found to be increased in some species, and the effect of temperature was significant. These results indicate several possible options for storing decontaminated waste, and have also been published in journals as original articles.

Based on the adsorption-desorption properties of radiocesium in relation to soils, absorbents, incineration ashes and tsunami deposits were estimated by performing the batch-absorption test to yield expected adsorption of radiocesium in landfill sites. Because the concentration of salts, especially the potassium salts, was quite high in the leachate from incineration ash, the adsorption capacity in the leachate tended to be lower than that in the seawater. These absorption reactions also have significant rates of reaction, requiring 10 hours to achieve the absorption capacity, explained as a distribution coefficient. This rate of reaction should be considered in the adsorption of radiocesium onto a thin layer absorption sheet. These results have been published in journals as original articles. They can contribute to the development of a design concept for the adsorption soil layer and its application to several new and existing landfill sites.

(2) Development, upgrading and evaluation of waste treatment, recycling and disposal technologies

(See chapters 4 and 5 for more details)

Several control technologies using thermochemical and physical processes for separation, solidification, and isolation of radioactively contaminated off-site waste as part of the solid waste management (including storage, treatment, recycling and final disposal) were developed and improved. The applicability of these technologies was evaluated in the laboratory through demonstrations and in relation to the overall design of the whole system.

A fly ash washing technique was established using the bench-scale test set for a municipal solid waste incineration plant. Performance guidelines were compiled by organizing the study group working on fly ash washing technology. A summary of several notices for the dismantlement of the plant was also compiled. An alert system for a leachate treatment plant to monitor radiocesium at concentrations below the effluent standard was developed and tested at a landfill site. Preparations and responses to an alert were compared based on their efficacy and efficiency.

Decontamination methods and the recycling guidelines for massive quantities of radioactively contaminated concrete waste were summarized. The mechanism of cesium penetration into concrete was clarified through measurements of contaminated concretes and by a penetration experiment using radioisotopes. Insolubilizing technologies for radiocesium, including application of nickel ferrocyanide, and their performances, were summarized. These technologies can also be applied to on-site radioactive waste from nuclear power plants.

Information was compiled on concrete technologies for the construction of the designated waste landfill. This material will be used as inputs for actual construction and management operations for the intermediate storage facility. The interaction between fly ash containing a larger quantity of soluble salts and the concrete was experimentally investigated and several countermeasures were developed. A plan to acquire data for long-term maintenance of concrete products using disposal facilities was also prepared.

The permeability of aquiclude final covers for land disposal of the specified waste was tested at a demonstration site. The safety of stored decontamination and putrefactive waste that was compressed and volume-reduced was also tested at a demonstration site. The long-term stability of the cement solidified radioactively contaminated waste was investigated by performing a repetitive dry-wet test. Rates of leaching obtained through the batch leaching test were reproduced in penetration processes of the column leaching test. A model representing the suppression effect of solidified waste size on leaching was established. These results were reflected in the standard specification of facilities.

(3) Development of technologies for long-term maintenance of waste management facilities

Methods for the long-term maintenance, dismantling and closing of thermal treatment and land disposal facilities for radioactively contaminated off-site waste were investigated. These are based on data acquired on the accumulation and movement of radioactive substances within facilities and an understanding of the nature and mechanisms of those phenomena.

The presence and movement of the radiocesium within the heat resistance material component of thermal treatment facilities for radioactively contaminated waste and decontamination waste were examined. Leachability and the effect of thermal cleaning of radiocesium within the heat resistance material were also examined. These results will support the long-term maintenance of facilities and the safer disposal of the heat resistance material.

The method for analyzing the behavior of radiocesium within landfills containing the specified general and industrial waste and the designated waste was standardized and incorporated within software available online. This method has been applied in relation to landfilling of radioactively contaminated waste in several municipalities. We have also supported the inspection of landfills and the training of engineers for appropriate and long-term management of landfills containing specified wastes.

(4) Establishment of technologies for measuring and monitoring radioactively contaminated off-site waste

Several methods for measuring and analyzing the dose rate and/or the radioactive concentration in waste related samples were evaluated. Knowledge relating to standardization and systematization of proper measurement, analysis and monitoring methods, including sampling methods for specific purpose were summarized.

Various measuring devices, including new products such as the scintillation fibers and the flexible container monitors were applied at several sites. The precisions of analysis methods related to sampling, preparation, and measurement of radiocesium and other nuclides were assessed. These results were incorporated in manuals on measurement methods compiled by the Japan Society of Material Cycles and Waste Management and the Ministry of the Environment.

(5) Establishment of a control framework for flows and stocks of radioactively contaminated off-site waste

(See chapter 6 for more details)

The flows and stocks of radioactively contaminated off-site waste and the component radioactive substances during waste recycling and disposal processes were estimated. A framework of measures required for the comprehensive management of off-site radioactive substances was developed.

The rates at which radiocesium migrated to the collected municipal solid waste and sewage sludge, and their interannual and seasonal variation after the FDNPS accident were analyzed. Data on transactional flows of waste and by-product around Fukushima Prefecture were compiled and recorded in the physical input-output table (PIOT) that described interchanges of material between sectors. The relationship between the radioactive concentration of waste and the air dose rate at the point of its generation was analyzed and used to calculate the quantity of radiocesium from the weight in the PIOT. A flow-stock analysis model was constructed and integrated with the radiation dose estimation tool for waste management for application within case studies.

(6) Establishment of method for risk communication

To establish risk communication between communities and the wider society, basic factors including inhibitors and accelerators were considered and technical information relating to risk communication was provided.

To establish the credibility of an information source, their provision of equitable, useful, and meaningful information to citizens was important. Means for increasing the utilization were required for the use of information provided by academic institutions, which have are at an advantage in their ability to issue information to a high degree of accuracy and expertise. Know-how and expertise regarding procedures for future disaster waste management was achieved through an understanding of the temporal transition of social circumstances in Fukushima Prefecture and through an investigation into procedures for implementing risk governance related to the radiation.

1.2.2 Environmental Recovery Research 2 ”Study of the dynamics of radioactive materials in multimedia environments”

We conducted research in areas such as the quantitative evaluation of radioactive Cs flow and stock in watersheds, development of a multimedia environment model; impacts on organisms and ecosystems; and radiation exposure evaluation - contributing to decontamination operations and other disaster zone environmental restoration processes by providing our research findings to the Ministry of the Environment, to Fukushima Prefecture, and to other parties.

(1) Environmental dynamics measurement

(See chapters 2 [2], 7 and 8 for more details)

We investigated the environmental dynamics of radioactive substances in forests, rivers, lakes, marine and other environments in order to ascertain their distribution, movement and accumulation and obtain measurement data to develop a multimedia environmental model.

We investigated the behavior of radioactive Cs in forests, and confirmed that regardless of the level of contamination, Cs outflow rate is very limited (less than 1% per year) compared with the amount deposited. We also determined Cs outflow characteristics according to the chemical form of Cs, and quantitatively evaluated the contribution of organic materials (plant detritus) in soil to Cs outflow.

We investigated the dynamics of radioactive Cs in inflow waters, and established by means of a quantitative evaluation of Cs deposition history in bottom sediment that direct fallout and initial inflow accounted for a much larger part of total Cs deposition from the nuclear power plant accident than the contribution of post-accident sediment inflow. We also demonstrated the role that dam reservoirs can play in preventing the spread of radioactive Cs to downstream inhabited regions.

We investigated the migration and accumulation of radioactive Cs at watershed level by analyzing stock and flow in the Utagawa and Kasumigaura watersheds, and clarified the current status and long-term trends of Cs movement and accumulation.

(2) Multimedia environmental modeling

(See chapters 2 [3], 9 and 10 for more details)

We have been developing a multimedia fate model for radioactive substances by combining models for atmospheric, oceanic, and terrestrial environments. The atmospheric and the oceanic models have been developed based on a regional atmospheric transport and deposition model for air pollution and a coastal sea model for water pollution, respectively. The terrestrial model has been developed based on the multimedia fate model G-CIEMS (Grid-Catchment Integrated Environmental Modeling System), which was originally developed for risk assessment of organic pollutants. We aimed to simulate the multimedia fate of radioactive substances by coupling the three models with appropriate grid-based and geographic resolutions.

In the immediate aftermath of the accident, we simulated the atmospheric transport and deposition of ^{137}Cs and ^{131}I emitted from the FDNPS. The model approximately reproduced the observed temporal and spatial variations of deposition rates in eastern Japan. This was a first finding of atmospheric behavior of radioactive substances on a regional scale, and consequently gave rise to significant public concern following a press related release. The simulated data were used for decision making with regards to measures for radioactive contamination of water and land.

We revised several model parameters related to ^{137}Cs fates for G-CIEMS based on observation results and published related reports; set up the physicochemical properties of ^{137}Cs; and input data on deposited ^{137}Cs based on simulation by atmospheric model. Simulation was performed for a period covering 9 years following the accident for predicting the annual average of ^{137}Cs remaining in land area, surface water, and surface-water sediment. The results showed that 70% of the total deposited ^{137}Cs on the land surface was in forest area.

The objective of the ocean modeling study was to evaluate and predict the oceanic ^{137}Cs behavior and its impacts on marine ecosystem in the coastal shelf from the nuclear power plant accident into the future. We have developed a comprehensive numerical model of the oceanic ^{137}Cs behavior focusing on its dynamics including advection-diffusion transport caused by water currents, adsorption/desorption to/from particulate matter, and sedimentation/suspension interconnected with vertical activity profile in the sediment.

(3) Impacts on organisms and ecosystems *(See chapter 11 for more details)*

We conducted field surveys and experiments on plants and mammals to detect genetic and other impacts of radioactive material released into the environment on organisms and ecosystems. We also conducted research on predicting changes in ecosystems and damage caused by wildlife in districts from which human inhabitants have been evacuated so as to propose management strategies.

We created genetically modified plants that enable evaluation of repair of damage to DNA caused by radiation, and demonstrated that plant DNA damage due to radioactive substances in soil is quickly repaired. We are now in the process of establishing an experimental system capable of DNA damage evaluation in the field.

We found oxidation of sperm DNA in the large Japanese field mouse (*Apodemus speciosus*) captured in the wild in high-dose areas, but the sperm showed no morphological abnormalities. To investigate whether this oxidation was inducing genetic mutations, we completed a draft sequence of the large Japanese field mouse genome, and are evaluating the genetic diversity of individuals trapped in the radioactively contaminated zone of Fukushima Prefecture.

Our monitoring activities for aquatic organisms revealed that radioactive Cs accumulation varies by species and functional group, and that metabolic rate is an important factor affecting accumulation. We will determine the mechanisms whereby radioactive Cs accumulates in fish and other aquatic organisms inhabiting both marine and freshwater environments.

We are developing a means for collecting and promptly releasing monitoring data on mammals, birds, amphibians and insects. We will also develop a mathematical model of the ecosystems of Fukushima Prefecture to enable prediction of changes in ecosystems resulting from the evacuation of human inhabitants.

(4) Evaluation of human exposure to radiation

(See chapters 10 and 12 for more details)

To evaluate human exposure to radioactive substances released into the environment, we measured environmental radiation levels including those of residential environments, and built a radiation dose estimation model that we used to carry out long-term, wide-area analysis of radiation doses. We also worked on the development of methods for measuring radioactive substances in the environment.

To provide scientific data that will help with long-term human radiation exposure prediction and reduction of radiation sources, we integrated modeling with monitoring to build a model for evaluating human radiation dose estimates, and analyzed radiation dose in detail.

Using our radiation dose estimation model, we estimated the distribution of radiation dose to inhabitants of eastern Japan for the first year after the nuclear power plant accident. We compared our model estimates with publicly available radiation dose data, and found that for external exposure, our estimates were consistent with actual measurements. While reviewing our data and fine-tuning parameters, we will also integrate this model with our multimedia environmental model to estimate radiation distribution and long-term radiation doses.

For monitoring, we measured actual radioactive Cs in indoor dust to set model parameters, and evaluated radiation doses and sources in Fukushima Prefecture and hotspots in the Kanto region (Tokyo and surrounding prefectures).

1.2.3 Environmental Renovation Research "Promotion of surveys and research towards restoration and environmental creation for the post-disaster regional environment"

The Environmental Renovation Research Program aims to promote surveys and research relating to projected future scenarios that focus on the restoration and reconstruction of the post-disaster regional environment. Accordingly, the project will investigate systems for developing regional socioeconomic and technological models, and for restoring social capital damaged by the disaster, as well as produce the design of a recovery center considering landuse planning in municipalities within Fukushima Prefecture. The scenarios developed within the project will be examined jointly with policymakers from the collaborating municipality (Shinchi Town in Fukushima Prefecture). They will be assessed based on local needs, while ensuring compatibility with existing regional plans and low-carbon technology scenarios.

(1) Development of local information systems for environmental creation

(See chapter 13 for more details)

From the perspective of efficient use of limited resources and energy, much attention has been focused on distributed regional energy systems. These systems enable the efficient use of both electricity and heat by facilitating the practical application of regional resources and by taking advantage of the geographical proximity between supply and demand locations. Compared with a large-scale centralized system, the planning and operation of a region-specific system, based on conditions within a district, assumes importance within a distributed system. However, most systems to date have been primarily designed and operated based on individual experiences, therefore hindering the production of general knowledge. For this study, we established a framework to support the design of a distributed energy system using a quantitative methodology. We confirmed its effectiveness through a case study of an actual district renovation project conducted within a municipality recovering from the GEJE. We further proposed expansion of the core project through an urban development plan based on a long-term perspective. One of the available options would be to expand the project to encompass overall planning of the entire town, including the industrial park.

For a distributed energy system installed at recovering areas, potential supply of various types of biomass were assessed in the eastern region of Japan. Promoting of biomass use may result in degradation of ecosystems and biodiversity. We also assessed effects of biomass use on ecosystems by using proxy variables for ecosystem services mapped for Japan's eastern region. These indices were analyzed using a multivariate statistical technique to identify specific key factors relating to the use of biomass and ecosystem services. Priority areas for the supply of biomass energy and ecosystem services were indicated and used to analyze potential conflicts between the two.

<u>(2) Development of models for analyzing regional environmental creation scenarios</u>

(See chapters 2 [4], 14 and 15 for more details)

From the perspective of local governments of areas devastated by the tsunami disaster, the process of recovery also provides an opportunity to establish a new energy system that is more efficient and self-sufficient; create new local businesses; and facilitate the lowering of emission levels of greenhouse gases (GHGs). Another important issue is to curb the trend towards depopulation already in evidence before the disasters.

To support the development of plans aimed at achieving the above targets, we developed a quantitative methodology that considered population, employment, industry, energy demand and supply, and energy technologies in a consistent and integrated manner. Applying the methodology to the town of Shinchi in Fukushima Prefecture,we developed scenarios for the town by 2050. In the "business as usual" scenario, the population would ultimately decline to almost half of the current level. The declining trend could be reversed in a scenario entailing the strategic location of industries based on industrial symbiosis. This would lead to efficient use of energy and more local energy-related industries, including smart network operators, co-generation facilities, and renewable energy producers.

For the analysis of optimal energy systems based on local characteristics, a bottom-up technology selection energy system model was developed for the town. In the baseline case, CO_2 emission would remain at around 50 kt-CO_2/y in 2050. CO_2 emission could be reduced by 80% through the installation of regional energy facilities such as solar photovoltaics and combined heat and power plants.

<u>(3) Development and implementation of participatory environmental creation methods</u>

Shinchi is implementing a program aimed at creating a "Smart Hybrid Town" based on environmental, economical, and social values associated with a "Future City." In close collaboration with Shinchi, we developed the "Shinchi Life Assist Tab System" that includes two assist functions: "Local energy assist" and "Life assist." For this study, we programmed tablet computers to display energy consumption information for residential houses and public facilities and established a regional ICT system to share information on town development during the reconstruction process. Our main objectives were as follows: 1) to promote eco-friendly action through the use of local information, 2) to streamline the use of local on-demand transit, 3) to support reconstruction efforts by victims of the earthquake, and 4) to share information interactively among regional stakeholders. To promote energy conservation activities among residents, we conducted experiments in the form of campaigns in September 2014, November 2014, and March 2015. The maximum average power saving rate was 7% of the September rate. In parallel, we carried out several questionnaire surveys and interviews. Their results suggested that the behavior and consciousness of the residents regarding an eco-friendly lifestyle were influenced by regional characteristics.

1.2.4 Environmental Emergency Management Research "Studies on establishment of the

environmental management system prepared for future disasters"

The GEJE caused extensive damage, including societal and environmental impacts, to Japan. Mitigation of the extent of the disaster's impact on society, and facilitation of expedited recovery from this damage are contingent on the resilience potential of Japan's social and technological systems. Accumulated knowledge and lessons, based on experiences of previous disasters including the GEJE, can contribute to strengthening the resilience potential of these systems.

For the Environmental Emergency Management Research Program, we conducted three research projects as outlined below.

<u>(1) Implementation strategy for resilience in material cycle and waste management</u>

(See chapters 2 [5], 16 and 17 for more details)

Appropriate quantitative and qualitative estimation of disaster waste generation is essential for formulating a disaster waste management plan. We obtained a unit factor for disaster waste generation based on our study of the consequences of the GEJE. Applying this to future disaster scenarios such as earthquakes in the Nankai Trough and in the Tokyo Metropolitan Area, we developed a new methodology for estimating the disaster waste which could be generated by projected future disasters.

Regarding appropriate disaster waste management technologies, we performed a pilot investigation of mechanical and manual segregation of disaster waste. We established a methodology for optimizing processes according to the type of disaster waste as well as the purpose of respective processes, for example, incineration and recycling. Regarding the management of hazardous material, including disaster waste, we focused on waste containing asbestos. We developed a rapid screening method for this kind of waste and investigated asbestos material dispersion during crushing and segregation processes, including improved control measures to prevent the dispersion of asbestos into the environment. Based on our results, we proposed appropriate measures for controlling the environmental impact of asbestos-containing material in disaster waste management. Regarding the recycling of disaster waste, we carried out a cost–benefit analysis for the use of disaster waste as recycled material to restore damaged infrastructure, and compiled data through a field investigation of a pilot embankment site.

In addition to these studies, we developed guidelines on the use of disaster waste. For the proper treatment of domestic wastewater, including human nightsoil, in the context of disaster management, we proposed a countermeasure against liquefaction caused by the earthquake's impact on a *Jokasou* system which is a uniquely Japanese domestic wastewater treatment system. We further formulated an estimation scheme for assessing the earthquake-resistant capacity of a *Jokasou* system.

Concerning management of organizational and human resources within local governments for disaster waste management, we outlined the necessary disaster waste management operations, to be conducted within a set time frame, and systematized several different operations within an organizational function. We further proposed a number of basic principles that should be considered when establishing a disaster waste management plan.

The abovementioned research outputs were reflected in relevant technical documents pertaining to national and regional level guidelines on disaster waste management.

<u>(2) Health and environmental risk management strategies in environmental emergency</u>

We discussed and proposed an environmental survey system to be applied in an emergency situation following the occurrence of a disaster. A particular discussion focus was on how to select and analyze target substances at the time of an emergency. We also collected relevant information from the US Environmental Protection Agency and the German and Canadian environmental ministries.

Moreover, we conducted several environmental monitoring surveys that focused, for example, on airborne particulates, long-term changes in a tidal flat ecosystem, and marine sediment contaminated with residual oil in the area affected by the tsunami disaster.

<u>(3) Development of exchange and networking for disasters and environment</u>

We held a workshop to identify and outline necessary capacities of local government personnel for disaster waste management in the event of an emergency. Personnel who had previous experience of actual disaster waste management following the GEJE participated in the workshop. As a result of the discussions at the workshop, we were able to systematically organize the required capacity elements. Based on our research findings, we designed and proposed a comprehensive training program. We further developed and conducted a training workshop as the central component of the proposed program. The impact of the training methodology was evaluated and subsequently improved.

Last, we established and disseminated outcomes and other information through a website serving as an information platform for disaster waste management. The website is expected to serve several purposes in facilitating preparion for future disasters. For example, it could support the development of disaster waste management plans by local authorities.

2. Research budget, human resources, and research papers published from FY 2013 to the present (mid-FY 2015)

Research budget per each fiscal year

	FY2013	FY2014	FY2015
Grant for Operating Costs	274	833	804
Other External Research Funding	820	58	-
Total	1094	891	804

(Unit: million-yen)

Human resources

Cumulative total number of staff : 327

Total number of research papers and conference presentations

Papers		Books	Presentations		Patents
Peer review	Others		Domestic	International	
59	122	13	453	70	4

Major papers and patents

Environmental Recovery Research 1: Thermal treatment of radioactively contaminated waste

[1] Kuramochi H. (2014) Thermal treatment of waste contaminated with radioactive chemicals due to the accident at Fukushima nuclear power stations: A review of recent research findings and introduction of some key literatures. Journal of Society for Remediation of Radioactive Contamination in Environment, 2, 71-84. (in Japanese)

This study investigated the distribution of radioactive cesium (r-Cs) between fly ash and bottom ash discharged during the incineration of r-Cs-contaminated municipal solid waste (MSW). To understand the behavior of r-Cs during the incineration of MSW, the stoker-type incinerator was simulated using a multi-zonal equilibrium calculation. This reasonably represented r-Cs distribution between the two forms of ash. The r-Cs accumulated within refractory bricks collected from MSW incineration facilities was examined by measuring r-Cs activity extending from the surface to the bulk of the bricks. Differences were found in the chemical forms of the accumulated r-Cs within portions of the bricks.

Environmental Recovery Research 2: Environmental dynamics measurement

[2] Nishikiori T., Watanabe M., Koshikawa M.K., Takamatsu T., Ishii Y., Ito S., Takenaka A., Watanabe K., Hayashi S. (2015) Uptake and translocation of radiocesium in cedar leaves following the Fukushima nuclear accident. Science of the Total Environment, 502, 611-616.

To understand the migration and accumulation of radioactive Cs in environments, we conducted field measurement studies in a forest and water body. In a forest, ^{137}Cs was absorbed through the surface of cedar tree leaves soon after the FDNPS accident. A further finding was that ^{137}Cs in new leaves that sprouted after the accident mainly resulted through a process of translocation from the old leaves.

Environmental Recovery Research 2: Atmospheric measurement and modeling
[3] Morino Y., Ohara T., Nishizawa M. (2011) Atmospheric behavior, deposition, and budget of radioactive materials from the Fukushima Daiichi nuclear power plant in March 2011. Geophysical Research Letter, 38, L00G11.

To understand the atmospheric behaviors and impact of radionuclides, we conducted atmospheric modeling of radioactive materials immediately after the nuclear accident at the FDNPS. Regional transport modeling played key roles in understanding the atmospheric behaviors and deposition patterns of radioactive materials. The model roughly reproduced the observed temporal and spatial variations of deposition rates of ^{137}Cs and ^{131}I in eastern Japan. This is a first publication of atmospheric simulations on a regional scale.

Environmental Renovation Research: Feasibility assessment of regional energy system
[4] Togawa T., Fujita T., Dong L., Fujii M., Ooba M. (2014) Feasibility assessment of power plant source waste heat to plant factory considering spatial configuration, Journal of Cleaner Production, 81, 60-69.

Japan has faced with multiple challenges of energy system transformation and social decarbonization in the post-Fukushima era. In revitalization area from the GEJE, it is a crucial argument to develop sustainable and low-carbon regional systems. For this sake, an urban energy model was constructed and combined with spatial analysis. The findings of the study indicated that the waste heat system provided more environmental benefits compared with the individual boiler system. Cost-effective areas regarding the heat supply were identified based on cost–benefit analysis and geographic information system techniques.

Environmental Emergency Management Research : Disaster waste management
[5] Tajima R., Hirayama N., Osako M. (2014) Identifying emergency support functions for disaster waste management - Structuring the practical tasks undertaken in the case of Great East Japan Earthquake-, Journal of Japan Society for Natural Disaster Science, 33, special issue, 153-163. (in Japanese)

To enhance smooth and appropriate disaster waste management (DWM), this paper aimed to identify fundamental emergency support functions necessary for DWM by structuralizing actual DWM tasks observed in the case of GEJE. The analysis revealed 22 sub-functions organized under 5 basic functions (namely, operations, command, logistics, finance/administration, and planning), which could be used as a basis of preparedness actions including planning response actions and designing functional organizations for effective DWM.

Detailed Research Outcomes

3. Understanding the behavior of radioactive cesium during incineration of contaminated waste and its accumulation in refractory materials used in waste incinerators

3.1 Behavior of radioactive cesium in waste incineration facilities

Three stoker-type incineration facilities for municipal solid waste (MSW) treatment in eastern Japan were studied to assess the amount of MSW that they process, the solids materials that they discharge such as ash and incombustible residue, and the MSW radioactivity. We calculated the distribution ratio of radioactive cesium (r-Cs) between two solid materials that were discharged from the incinerators (see Fig. 3.1). The distribution ratio of fine dust in the flue gas, such as fly ash (FA) and ash-melting FA, was higher than that of the solid material discharged from the bottom of the incinerator, such as bottom ash (BA) from stoker-type incinerators, incombustible residue from fluidized-beds, and slag from ash-melting processes. However, the FA ratio depends on the incinerator type as follows; its value for FA discharged from a fluidized-bed as well as ash-melting FA is higher than that for FA from a stoker-type incinerator. For the ash-melting process, the treatment temperature is much higher than that of the incinerator, and results in the promotion of vaporization of r-Cs chemicals into the flue gas. The high ratio of FA formation from fluidized beds results from the mechanical blowing of most of the MSW ash content that contains r-Cs into the flue gas.

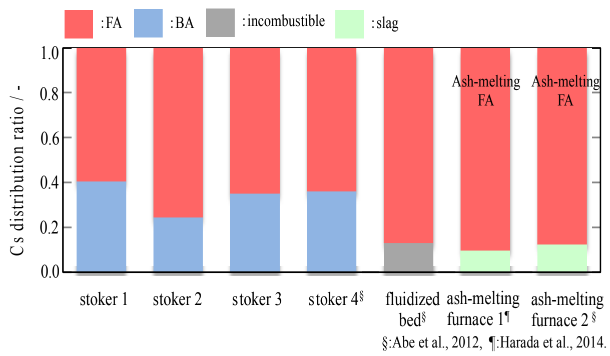


Fig. 3.1 Distribution ratio of r-Cs between solid materials discharged from MSW incinerator.

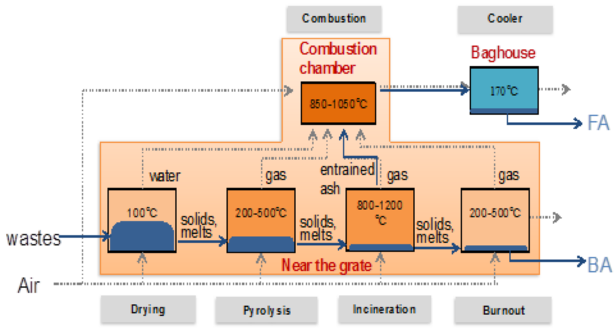


Fig. 3.2 Schematic of multi-zonal equilibrium calculation (incineration simulator) for stoker-type incinerator.

3.2 Development of incineration simulator

To understand the behavior of r-Cs in MSW incineration facilities and what r-Cs compounds transform to 3during incineration, we developed an incineration simulator for stoker-type incinerators based on the multi-zonal equilibrium calculation method proposed by Ginsberg et al. (2012). In the simulator, as shown in Fig. 3.2, the stoker-type incinerator is divided into several functional zones such as drying, MSW pyrolysis, and MSW incineration. Thermodynamic equilibrium calculations are performed and the calculation result for one zone is used as input to the subsequent zone. The simulator represents the concentration of major gas components in the individual zones reported in earlier works. In addition, the calculated distribution of r-Cs between BA and FA agrees well with the distribution measured in our investigation as shown in Fig. 3.3. Figure 3.4 shows chemical Cs species and their production amount in each zone. r-Cs forms cesium chloride and aluminosilicate in FA, while the only aluminosilicate is formed in BA. The difference in chemical form can account for differences in r-Cs leachability between BA and FA. Use of our simulator may suggest a method to control the r-Cs distribution between FA and BA and their leachability. In the future, it will be applied to represent the accumulation of r-Cs into refractory materials in the MSW incinerator described in the next section.

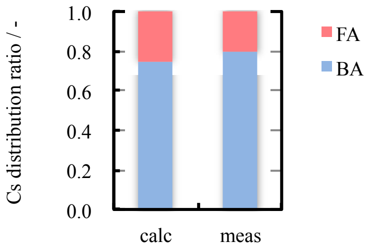


Fig. 3.3 Distribution of Cs between FA and BA calculated by the developed incineration simulator and comparison with the measured distribution.

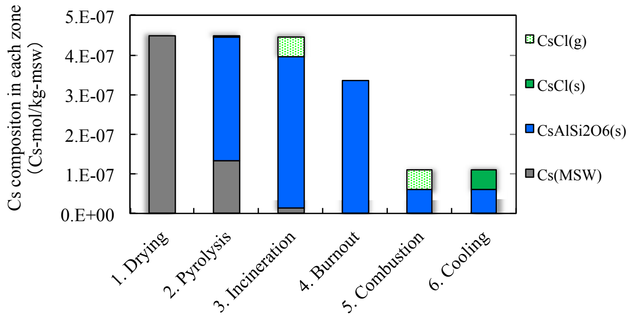


Fig. 3.4 Chemical species of cesium (Cs) in individual zones and their production calculated by developed incineration simulator. g: gas, s: solid.

3.3 Accumulation of r-Cs in refractory materials

We surveyed the accumulation of r-Cs in refractory brick samples used in MSW incineration facilities. As shown in Fig. 3.5, r-Cs was detected in all portions from the surface to the bulk of the bricks, which corresponds to the inner to outer portion of the incineration furnace. The surface r-Cs concentration at the inner furnace wall was higher than that in the others towards the bulk side. Figure 3.6 shows the accumulation profile of r-Cs for some bricks in different temperature zones in a facility. Lower brick temperatures result in higher r-Cs concentrations in the brick. A hotspot exists (a high-concentration area of r-Cs) in the MSW incinerator. We expect that exposure of contaminated bricks to a high temperature leads to their decontamination.

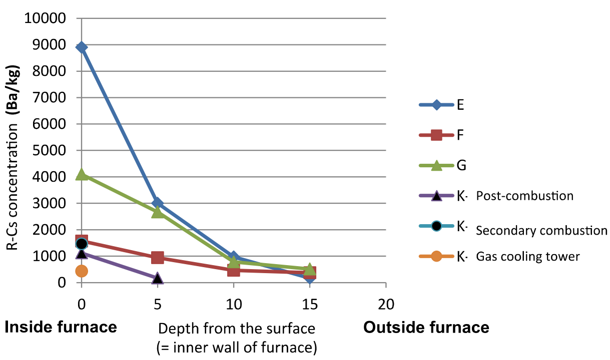


Fig. 3.5 Accumulation of r-Cs in refractory materials collected from various MSW incineration facilities.

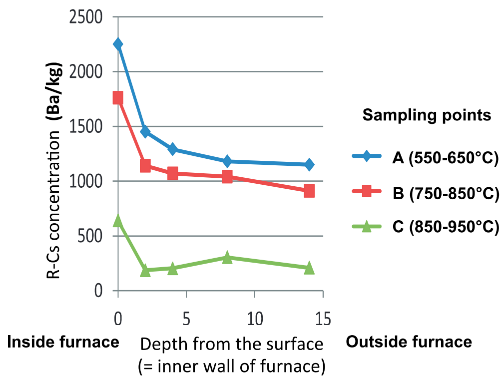


Fig. 3.6 Accumulation of r-Cs in various refractory materials in a MSW incineration facility.

We measured the time course of air dose inside and outside a MSW incineration facility for approximately 1 year. The air dose decreased significantly after replacing contaminated refractory bricks inside the incinerator with new uncontaminated ones. The air dose time course after the replacement increased slightly or gradually compared with the air dose before the replacement. This indicates that the air dose may be affected by MSW r-Cs levels, because the r-Cs concentration in the FA and BA decreased since the accident at the nuclear power station. These data are useful for safe maintenance and demolition of the waste incinerator.

3.4 Leachability of r-Cs from contaminated refractory materials

The leachability of r-Cs from contaminated refractory waste is important for designing appropriate treatment and disposal strategies. A leaching test for the aforementioned refractory materials was performed according to Notification No. 13 from the Ministry of the Environment. Test results for r-Cs leachability are shown in Fig. 3.7. The leachability data for refractories with Si content lower than 10% were scattered, whereas r-Cs scarcely leached from other refractories with Si contents of approximately 20%. The Si level may be a key factor for this leaching characterization. Different leachabilities among various refractory materials exhibit difference in r-Cs chemical forms among them.

Finally, we characterized the leaching behavior of several layers obtained from a refractory. Figure 3.8 shows the individual layer leachability. The layer close to the inside of the furnace had a very low r-Cs leachability. However, the leachability for others increased linearly towards the outside (red arrow). This indicates that the chemical form of r-Cs differs among those layers even if they originate from one refractory. This difference is considered to be because of a significant temperature depression from the surface to the bulk of the brick.

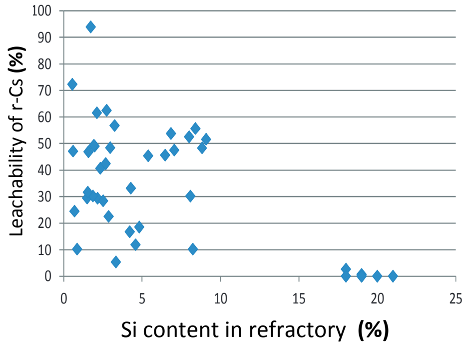


Fig. 3.7 Leachability of r-Cs from the refractory as a function of its Si content.

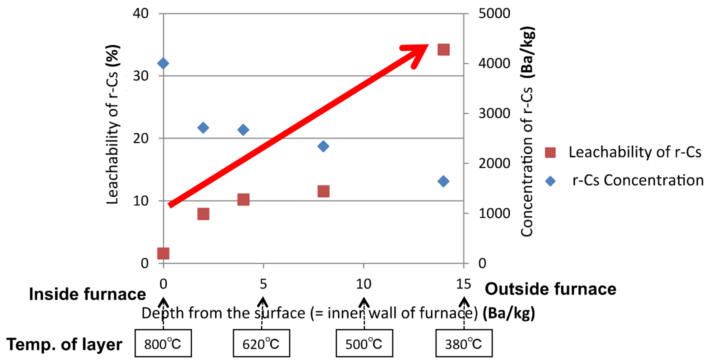


Fig. 3.8 Leachability of r-Cs for individual layers from a contaminated refractory.

[Reference]
Ginsberg, T., Liebig, D., Modigell, M., Sundermann, B. (2012) Multizonal thermochemical modelling of heavy metal transfer in incineration plants. Process Safety &Environmental Protection. 90, 38-44.

4. Radioactive cesium adsorption on soil and leaching from waste under landfill conditions

The "Act on Special Measures Concerning the Handling of Radioactive Pollution" was promulgated at the end of August 2011, and came into force on January 1, 2012. New waste classifications were added to the Act and these include specified waste, decontamination waste, specified MSW, and specified industrial waste. The specified waste includes designated waste, which is the waste that has an activity of more than 8,000 Bq/kg, and waste from special decontamination areas. The specified MSW and industrial wastes are MSW and industrial waste less than or equal to 8,000 Bq/kg, and the specified MSW and industrial waste are disposed of into ordinary MSW landfill sites and ordinary controlled-type industrial landfill sites, respectively. Because the specified MSW is disposed of into ordinary MSW landfill sites, some additional standards are added to prevent r-Cs leakage and radioactive exposure according to the Act, as shown in Fig. 4.1. Basic reasons for the additional standards include prevention of rainwater contact with the waste and r-Cs capture in the soil layer. To evaluate the safety of landfilling, we investigated the leachability of r-Cs from waste and r-Cs sorption ability of soils under landfill conditions.

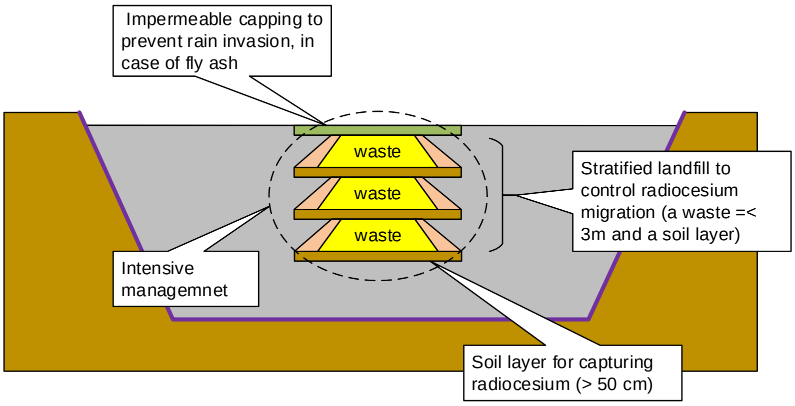


Fig. 4.1 Additional standards for specified MSW and industrial waste landfill

Agitation test JIS K 0058-1 item 5 was used as a leaching test method, in which the sample is used as-is. The agitation test method has the following features: no sample size reduction, a water mass that is ten times that of the sample mass, six hours of leaching, and 200 rpm agitation. BA and FA of the specified MSW were used as a leaching test sample. The leaching test results are shown in Fig. 4.2. To evaluate the long-term leaching behavior, we continued the leaching test for more than 6 hours and up to 90 days. Results of the long-term leaching test are shown in Fig. 4.3. We measured a stable isotope of cesium, ^{133}Cs, instead of r-Cs in case the latter concentration was below the detection limit. The r-Cs leachability of the FA was very high and 70–80% was leached within 6 hours. Most of the r-Cs is transferred into the water after several days. In addition, the electrical conductivity of the solvent increased to thousands of millisiemens per meter.

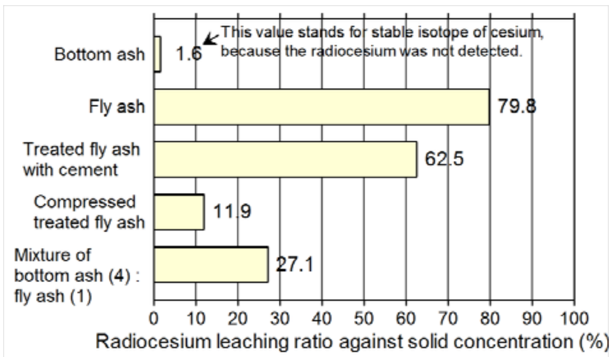


Fig. 4.2 Leaching ratio of specified MSW

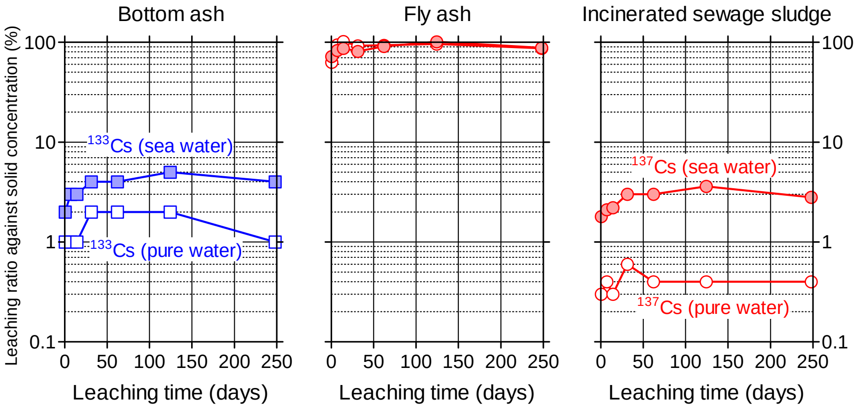


Fig. 4.3 Long-term leaching behavior of specified MSW

Specified MSW FA leachate (electrical conductivity = 4,200 mS/m, pH = 12) that included r-Cs was used as a solvent in the sorption test. The sorption test period was 1 day and a 120 rpm shaking method was used. To obtain a distribution coefficient, the liquid to solid ratio was varied from 8 to 2000. The distribution coefficient of various soils and granules is shown in Fig. 4.4. The distribution coefficient of soils against r-Cs is very high. Under FA landfilling conditions, however, it decreases from one tenth to one hundredth. Subject to the FA leachate, the distribution coefficient depends on the electrical conductivity of the leachate; when the electrical conductivity increases tenfold, the distribution coefficient becomes almost one tenth, as shown in Fig. 4.5.

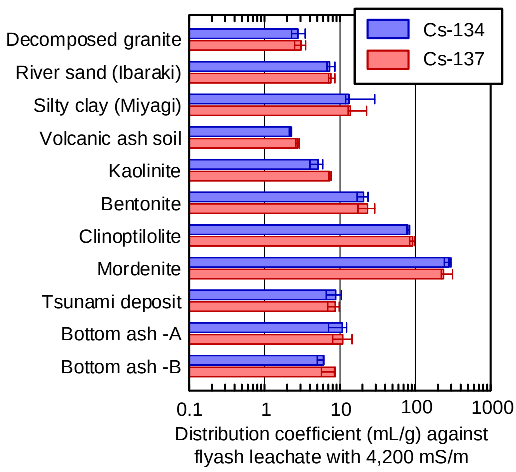


Fig. 4.4 Distribution coefficients under landfill conditions

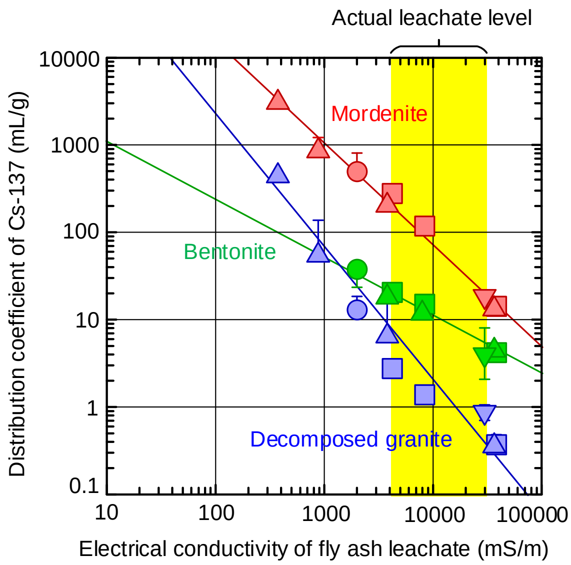


Fig. 4.5 Change in distribution coefficient of ^{137}Cs with electrical conductivities

5. Application of cement and concrete technology

5.1 Outline

It has been proposed that cement and concrete technology be used for remediation of nuclear power plant (NPP) accidents as shown in Fig. 5.1, where the environment is contaminated and various types of contaminated debris are generated. Among them, the safe and trusted treatment and disposal of incineration FA that contains concentrated r-Cs in water-soluble form and the volume reduction of concrete waste has been discussed.

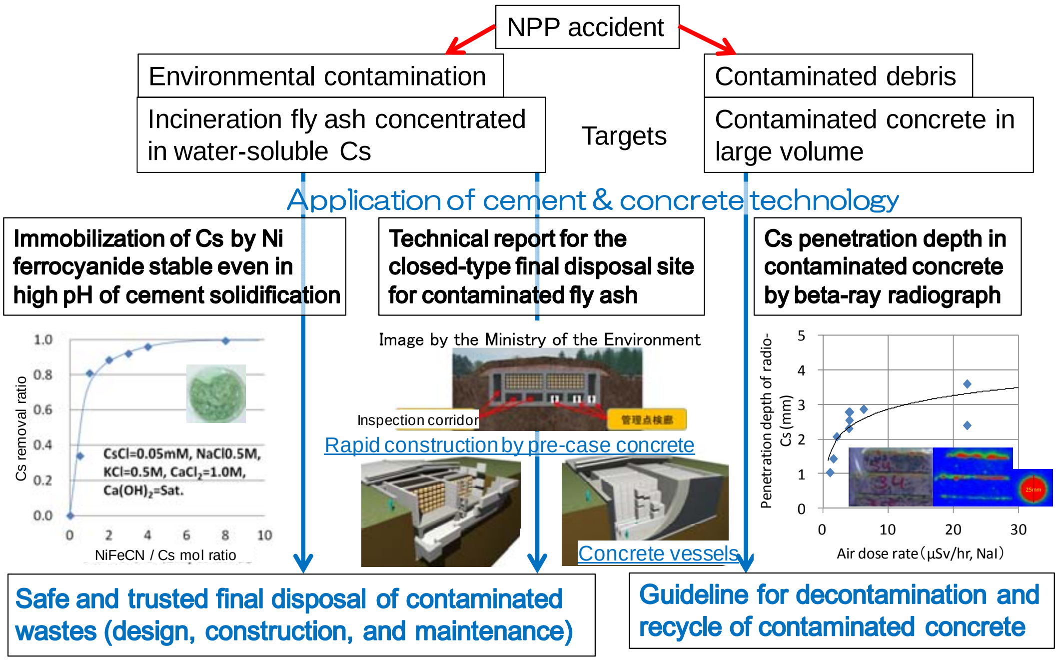


Fig. 5.1 Outline of application of cement and concrete technology for remediation

5.2 Concrete decontamination

Concrete forms a large part of various contaminated objects. The contamination is expected to exist mainly at the surface (Farfán et al., 2011). It would be possible to reduce the amount of waste if the surface-contaminated layer were removed by water-jet abrasion or some other method, because uncontaminated concrete wastes can be recycled as road construction materials. If the contamination level was limited, it could be possible to recycle concrete wastes after crushing without decontamination. For these procedures, knowledge of the contamination depth of r-Cs in concrete is essential.

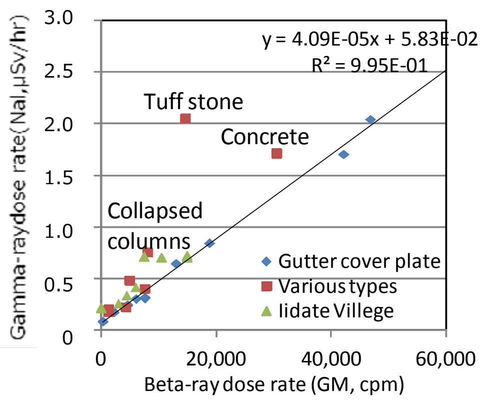


Fig. 5.2 Correlation between beta and gamma rays of various concretes in the field.

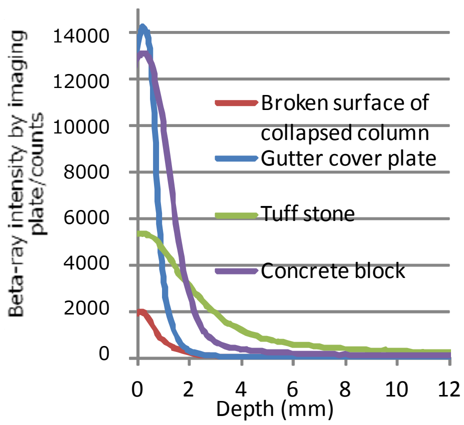


Fig. 5.3 Penetration profile of r-Cs by imaging plate for beta rays

As a first step, the penetration depth of r-Cs was evaluated in various concretes in Iitate and Okuma by comparing the dose rate of beta and gamma rays using GM and NaI survey meters, respectively. The correlation for both dose rates is shown in Fig. 5.2. A linear correlation exists for some concrete such as gutter cover plates or road. As is shown later, r-Cs is located at the surface in these cases. In other cases, the r-Cs has penetrated deeper to some degree. Because the beta ray penetration range is only 0.1–0.2 mm in concrete but is higher for gamma rays, if the r-Cs penetrates deeper, more gamma rays are detected than beta rays. So, the measurement by both methods can provide information as to whether the concrete contamination is limited to the surface or reaches deeper.

In the next step, concrete samples were taken from various concrete structures and processes to evaluate the penetration depth by beta ray radiographing using imaging plates. Concrete plates of 20 mm × 50 mm × 3 mm in size were placed on an imaging plate and their penetration profiles were obtained. In Fig. 5.3, the intensity profiles of the r-Cs are shown for typical concrete samples. For concrete gutter plates and columns, contamination is limited to 2 mm. However, for more porous concrete blocks or tuff stone, the penetration reaches 5 or 10 mm. In the final step, based on the concentration of r-Cs, a decontamination procedure will be proposed.

5.3 Requirements for closed-type final disposal site made of reinforced concrete for r-Cs-contaminated incineration FA

The Ministry of the Environment has proposed the preparation of a closed-type final disposal site made of reinforced concrete for relatively highly contaminated wastes such as MSW incineration (MSWI) FA. MSWI is the most popular way to reduce the amount of combustible waste in Japan. During incineration, r-Cs is concentrated 30 times and is converted to a water-soluble form in FA. To eliminate HCl gas generation during incineration, lime is added in a bag filter. Using the bag filter system, r-Cs can be captured in chloride form to a non-detectable level. Simultaneously, significant amounts of chlorides such as $CaCl_2$, NaCl, and KCl are contained. These salts affect the concrete structure durability. To prepare for the safe disposal of highly contaminated FA wastes, the basic characteristics of FA were clarified and a technical report on the design, construction, and maintenance of a closed-type final disposal site for contaminated wastes was written.

The waterproof nature of the site must be considered first. Top cover soil, bentonite-mixed soil, water-tight concrete, and a protective layer on the concrete can provide effective multiple water shields. However, to prepare for the worst situation where every shield experiences problems such as leakage and a highly concentrated chloride solution is generated, the durability of the concrete structure is discussed and countermeasures are proposed to obtain adequate time for repair.

[Reference]

Farfán, E.B., Gaschak S.P., Maksymenko A.M., Donnelly E.H., Bondarkov M.D., Jannik G.T., Marra J.C. (2011) Assessment of (90)Sr and (137)Cs penetration into reinforced concrete under natural atmospheric conditions. Health physics, 101, 311-320.

6. Analysis of radioactive cesium inflows to solid waste and water treatment processes and the accumulation of radioactive cesium in the waste generated

Large amounts of waste contaminated with r-Cs have been generated by MSW incineration, sewage water treatment, water purification, and other types of treatment processes over a wide area in eastern Japan since the accident at the Fukushima Daiichi Nuclear Power Plant (FDNPP). We analyzed the temporal and regional trends in r-Cs contamination of MSW incineration residues and sewage sludge and estimated the amounts of r-Cs entering MSW incineration and sewage treatment processes from the environment.

We identified temporal trends in the r-Cs concentrations in MSW incineration residues and sewage sludge generated since July 2011 by analyzing the combined results of measurements made at the MSW incineration and sewage treatment plants in 16 prefectures in eastern Japan (Fig. 6.1). The r-Cs concentrations (the sums of the ^{134}Cs and ^{137}Cs concentrations) in MSW incineration residues have decreased exponentially by an average of approximately 40% per annum, with seasonal fluctuations. Similar seasonal fluctuation patterns have occurred each year, the r-Cs concentration increasing in early summer (April–June) and decreasing in winter (January–March). We demonstrated that the temporal trend in the r-Cs concentration can be explained by three factors: a longitudinal decreasing trend in r-Cs inflows to MSW incineration processes, seasonal variations in r-Cs inflows, and the radioactive decay of r-Cs. The r-Cs concentrations in sewage sludge decreased significantly, by more than half, in the first 6 months after July 2011, but the r-Cs concentration has not decreased significantly since then. No clear seasonal fluctuations were observed in the r-Cs concentrations in sewage sludge.

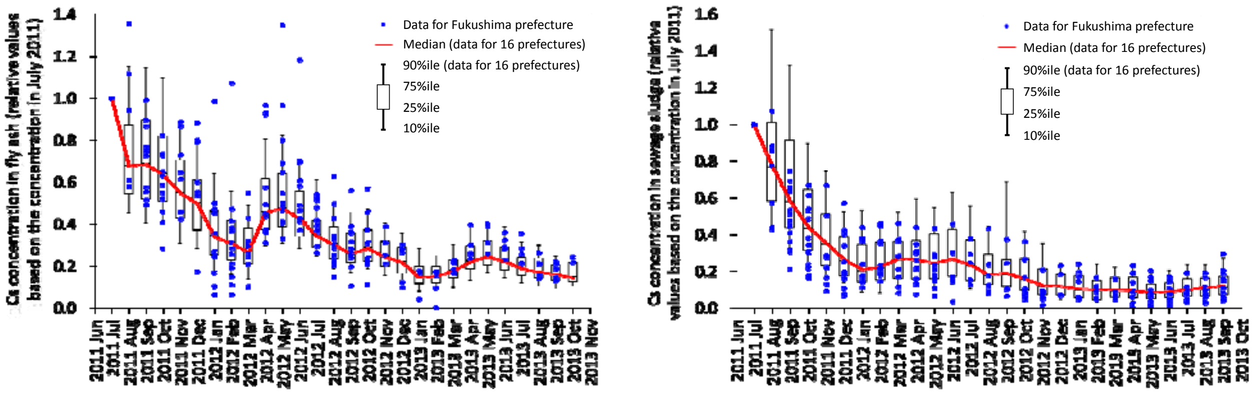


Fig. 6.1 Temporal trends in the r-Cs (total ^{134}Cs and ^{137}Cs) concentrations in fly ash produced in MSW incinerators (left) and dewatered sewage sludge produced in sewage treatment plants (right) in 16 prefectures in eastern Japan. The values shown are the concentrations found since July 2011 relative to the concentrations found in July 2011.

We also assessed the differences in the r-Cs concentrations in MSW incineration residues produced by different types of incinerator. The concentration rate of the r-Cs to the produced fly ash is clearly different for different incineration systems (stoker-type incineration, fluidized-bed incineration, gasification and melting, and incineration with ash melting), as shown in Fig. 6.2. We found that the different rates at which the r-Cs was concentrated to the fly ash can be explained by two factors: the different amounts of fly ash produced for each unit of MSW incinerated by different incineration systems, the different proportion of the r-Cs to be distributed to the fly ash produced through the MSW incineration (Fig.6.3).

From the results described above, we estimated the r-Cs inflows to the MSW incineration and sewage water treatment processes in 16 prefectures in eastern Japan. We estimated that 0.03%–0.05% and 0.5%–3% of the total amount of r-Cs deposition flowed into the MSW incineration and sewage water treatment processes in the year after July 2011, respectively. We also conducted a case study in which we calculated a preliminary estimate of the r-Cs flows through MSW incineration processes (Fig. 6.4). A large fraction of the r-Cs entering MSW incineration processes ended up in the landfill of incineration residues with r-Cs concentration not exceeding 8,000 Bq/kg (the limit for landfill at ordinary landfill sites) or were sent to temporary storage of incineration residues with r-Cs concentration exceeding 8,000 Bq/kg. Our preliminary estimate showed that a small fraction of the r-Cs entering MSW incineration processes later entered recycling processes, such as the production of construction materials, cement, and non-ferrous metal materials. We have been trying to produce more detailed estimates that reflect the actual disposal of residues in eastern Japan. We have developed a macroscopic model for analyzing r-Cs flows involved in the generation of various types of waste and the disposal and recycling of the waste.

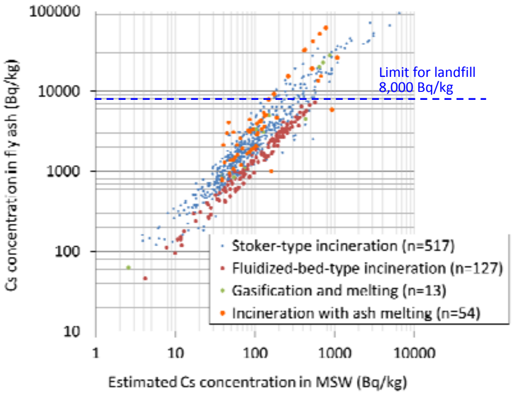


Fig. 6.2 Total r-Cs (^{134}Cs and ^{137}Cs) concentrations found in MSW incinerated and fly ash produced by different types of MSW incinerator.

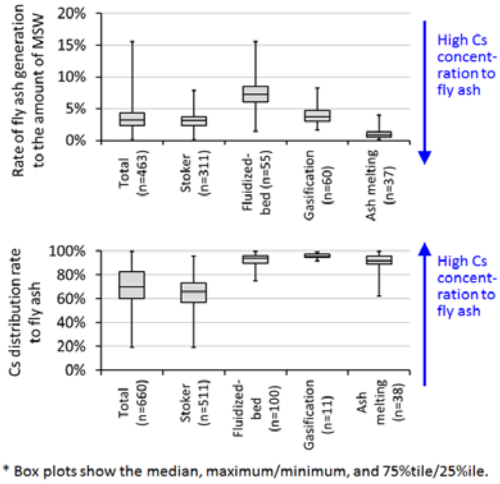


Fig. 6.3 Amount of fly ash produced as a proportion of the amount of MSW incinerated (upper plot) and the proportion of the r-Cs in the MSW distributed to the fly ash produced (lower plot) by different types of incinerator.

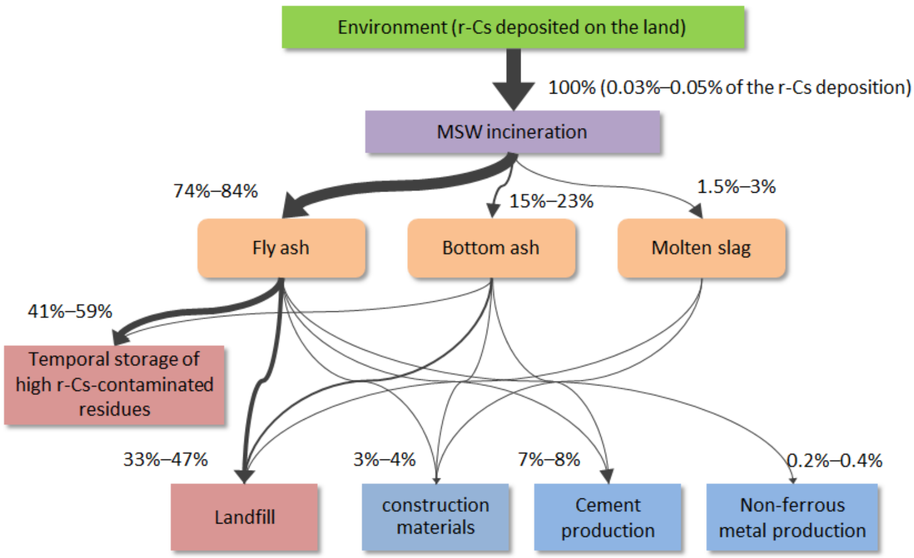


Fig. 6.4 Preliminary estimates of r-Cs flows through the MSW incineration

7. Behavior of radioactive cesium in forested areas

We conducted successive field measurements of the migration and accumulation of r-Cs in the Mt. Tsukuba area in Ibaraki Prefecture (a moderately contaminated site) and in the upstream part of the Uda River Basin (a heavily contaminated site) soon after the FDNPP accident to allow the behavior of r-Cs in forest ecosystems, from initial deposition to runoff, to be understood quantitatively.

7.1 Initial deposition

Throughfall and bulk precipitation were collected from the beginning of March to late April 2011. From the results of the analysis of these samples, the catchment-averaged initial amount of ^{137}Cs deposited onto the forest floor of a forest catchment in the Mt. Tsukuba area was estimated to be 11.6 kBq/m^2. More than 80% of the mean total ^{137}Cs concentration (75 Bq/L) at the six points that samples were collected from was found to be in the dissolved form. Less ^{137}Cs was found to be initially deposited onto the forest floor in a conifer plantation (containing *Cryptomeria japonica* and *Chamaecyparis obtusa*) than onto the forest floor in a deciduous forest and onto the ground in a neighboring open space. This was because the conifer canopy intercepted about 40% of the ^{137}Cs deposited to the conifer plantation. A large proportion of the ^{137}Cs intercepted by the canopy after the FDNPP accident had been washed out by throughfall and had migrated to the forest floor within 6 months of the accident.

7.2 Behavior in contaminated trees

The uptake and translocation of ^{137}Cs by *C. japonica* leaves was studied by analyzing the ^{137}Cs activity concentrations and the ^{137}Cs/^{133}Cs concentration ratios in old and new *C. japonica* leaves collected from a forest on Mt. Tsukuba between 9 and 15 months after the FDNPP accident. The ^{137}Cs and ^{133}Cs isotope concentrations in throughfall, bulk precipitation, and soil extracts were also determined, and these concentrations were used as proxies to assess the absorption of r-Cs from the leaf surfaces and through the root system. The ^{137}Cs/^{133}Cs ratios were considerably higher in leaves that had grown before the accident than in the soil extracts and lower in leaves that had grown before the accident than in throughfall and bulk precipitation. Large quantities of dissolved ^{137}Cs were deposited soon after the FDNPP accident, and this ^{137}Cs was available for foliar uptake, meaning that some of the ^{137}Cs in the old leaves had presumably been absorbed through the surfaces of the leaves. New leaves that had grown after the accident had similar ^{137}Cs/^{133}Cs ratios to the old leaves, suggesting that the uptake of ^{137}Cs through leaves and then translocation of the ^{137}Cs to other plant parts are important processes through which *C. japonica* plants become contaminated during or just after radioactive fallout incidents.

7.3 Accumulation in soil

The annual changes in the amounts of r-Cs accumulated in the soils in the forest catchments in the Mt. Tsukuba area and the upstream area in the Uda River Basin showed that more than 80% of the total amount of r-Cs deposited after the FDNPP accident was retained in the organic layer and in the soil up to a depth of 5 cm from the surface at most of the sampling sites, even three and half years after the accident. In particular, more than 60% of the deposited r-Cs was retained in the organic layer of the soil in the upstream area in the Uda River Basin, suggesting that the particulate organic matter derived from the forest litter strongly retained r-Cs and that the r-Cs migrated downward into the inorganic soil layers less strongly in this area than in the other study area. Our measurements in the Mt. Tsukuba area also showed that the migration of r-Cs to the forest floor in throughfall and litterfall from the canopy caused very strong r-Cs accumulation in the surface layer.

7.4 Runoff

We assessed the influence of vegetation on the wash-off of ^{137}Cs from forested areas by monitoring the amounts of ^{137}Cs in the eroded soil and surface runoff water from 3 m^2 experimental plots on 37–39° slopes in four different types of forest in Fukushima Prefecture for 145 days, from May to October 2013. The most ^{137}Cs was lost from plots in a Japanese cypress forest, followed by plots in a deciduous broadleaf forest, then a Japanese red pine forest, and then a Japanese cedar forest. The amount lost from the plots in the Japanese cedar forest was 10 times lower than the amount lost from the plots in the Japanese cypress forest. More than 96% of the ^{137}Cs lost by the plots was in the eroded soil, and relatively large amounts of soil were lost from the plots in the forests that did not have well-developed understories and/or had small organic horizons, suggesting that the forest floor covering strongly affected the wash-off of ^{137}Cs. Nevertheless, only up to 1.1% of the ^{137}Cs in the soil was washed off the plots. The ^{137}Cs activity concentrations correlated positively with the organic matter contents in both the eroded soil and the suspended solids in stream water, confirming that ^{137}Cs was transferred from the forest floor to streamwater and indicating that the organic horizon was an important source of the washed off ^{137}Cs.

A runoff study was carried out in forest catchments in the Mt. Tsukuba area and in an upstream area in the Uda River Basin to quantify the contribution of forest areas to the runoff of r-Cs deposited after the FDNPP accident. Less than 0.3% of the ^{137}Cs deposited after the FDNPP accident was estimated to be lost in the suspended solids in the runoff in each of the catchments each year, suggesting that runoff from forested areas is not an important source of r-Cs to the aquatic environment each year, regardless of how contaminated forested areas have become. Moreover, a significant positive relationship was found between the organic matter contents and the ^{137}Cs activities in the two suspended solid fractions that were analyzed (65 μm to 250 μm and 250 μm to 1 mm), suggesting that some of the r-Cs that was lost in runoff was adsorbed or otherwise associated with particulate organic matter.

8. Migration and accumulation of radioactive cesium in a river basin

We performed hydrological observations and collected river water samples and sediment cores to allow the stocks and flows of ^{137}Cs in the basins of Lake Kasumigaura (in Ibaraki prefecture) and Matsukawaura Lagoon (in the Fukushima coastal area) to be quantified. The aim was to gain an understanding of the dynamics of ^{137}Cs deposition that has occurred at the basin scale since the FDNPP accident.

8.1 Runoff of ^{137}Cs at the river basin scale

The weight concentration of ^{137}Cs in suspended solids (SS) sampled at a downstream point in each of the seven main rivers flowing into Lake Kasumigaura (which has an area of 172 km^2) and the Uda River flowing into Matsukawaura Lagoon (which has an area of 6.46 km^2) were measured. Strong positive correlations were found between the ^{137}Cs concentrations and the catchment-averaged amounts of ^{137}Cs deposited, but less significant correlations were found between the ^{137}Cs concentrations and the SS contents. The measured SS flux was multiplied by the ^{137}Cs concentration to estimate the proportion of the ^{137}Cs deposited that was lost in runoff each year. Annual runoff was estimated to contain between 0.12% and 0.42% of the ^{137}Cs deposited in the Lake Kasumigaura Basin (which has an area of 1,915 km^2) and to contain 0.12% of the ^{137}Cs deposited in the Uda River Basin (which has an area of 106.3 km^2), suggesting that the migration of r-Cs from contaminated land to the aquatic environment is very limited at the river basin scale regardless of the amount of contamination that has occurred.

8. 2 Role of a dam lake in the retention of ^{137}Cs

Sediment core samples were collected in 2012 and 2013 from the Matsugabou dam lake, which is in the upstream part of the Uda River. Analysis of these samples showed that the sedimentation of SS containing relatively low ^{137}Cs concentrations that currently flow into the dam during storm events shields the sediment layer that was highly contaminated with ^{137}Cs near the dam wall. The contaminated layer was formed because of direct deposition onto the lake surface at the time of the FDNPP accident and inflow of r-Cs from areas with impervious ground cover soon after the r-Cs had been deposited in those areas.

A ^{137}Cs balance of the dam lake was calculated based on continuous hydrological observations, and this showed that the reservoir function of the dam lake (i.e., control of the discharge volume) controls the migration of r-Cs to the downstream parts of the basin and causes more than 90% of the ^{137}Cs associated with SS that enters the lake each year to accumulate as sediment on the lake bed.

8.3 Analysis of the ^{137}Cs stocks and flows in Lake Kasumigaura Basin

The average amount of ^{137}Cs accumulated in sediment in Lake Kasumigaura was estimated by interpolating data with a spatial resolution of 250 m to be 17 kBq·m^{-2}. These data were obtained from measurements of ^{137}Cs activities in 15-cm-deep sediment cores from 68 points covering the whole of Lake Kasumigaura. The cores were collected in December 2012. The average amount of ^{137}Cs accumulated over the entire land area of the basin (14 kBq·m^{-2}) was calculated using data from an airborne monitoring survey. The percentage of the ^{137}Cs lost from the land in the basin to runoff each year was estimated to be 0.5%, from observations of the seven main rivers that flow into Lake Kasumigaura. Combining these estimates, we estimated that the total amount of ^{137}Cs that was lost from the entire land area of the basin to runoff was 1.7×10^8 kBq in the 21 months after the FDNPP accident. This corresponds to only 5.9% of the total amount of ^{137}Cs that had accumulated in the lake sediment after the FDNPP accident, indicating that ^{137}Cs in influent SS was a minor contributor to radioactive contamination in the lake sediment. The relatively large amount of r-Cs that has accumulated in the lake sediment is therefore likely to have entered the lake through direct deposition onto the lake surface at the time of the FDNPP accident and the runoff of r-Cs from areas in the basin that are covered with impervious surfaces (such as urban areas) soon after the r-Cs had been deposited in those areas.

8.4 Analysis of the ^{137}Cs stocks and flows in the Matsukawaura Lagoon basin

The average amount of ^{137}Cs accumulated in the Matsukawaura Lagoon sediment was estimated by interpolating data with a spatial resolution of 100 m to be 34 kBq·m^{-2}. These data were obtained from measurements of ^{137}Cs activities in 20-cm-deep sediment cores from 36 points covering the whole of the lagoon. The sediment cores were collected in July 2013. The average amount of ^{137}Cs accumulated over the entire land area of the basin (172.5 km^2) was calculated using data from an airborne monitoring survey to be 150 kBq·m^{-2}. The percentage of the ^{137}Cs lost from the land in the basin to runoff each year was estimated to be 0.12%, from observations at a point in the downstream part the Uda River, which flows into the lagoon. Combining these estimates, we estimated that the total amount of ^{137}Cs that was lost from the entire land area of the basin to runoff was 7.2×10^7 kBq in the 28 months after the FDNPP accident. This corresponds to about 30% of the total amount of ^{137}Cs that had accumulated in the lake sediment after the FDNPP accident, indicating that the ^{137}Cs concentration in the lagoon might increase in the future because ^{137}Cs may accumulate more quickly than it decays. This possibility is caused by the marked difference between the ^{137}Cs concentrations in the heavily contaminated mountainous upstream region and the moderately contaminated lowland downstream region. However, very limited migration of ^{137}Cs through the river basin has been observed so far. More detailed investigations, such as a continuous survey of ^{137}Cs accumulation across the lagoon bed and a quantitative evaluation of the amount of ^{137}Cs discharged from the lagoon to the sea, will be required to allow a more accurate understanding to be gained of the changes that will take place in the ^{137}Cs concentrations in the Matsukawaura Lagoon.

9. Multimedia fate modeling of radioactive substances

9.1 Three modeling studies

We have developed a multimedia fate model for radioactive substances by coupling atmospheric, oceanic, and terrestrial environment models (Fig. 9.1). The atmospheric and oceanic models were developed at the Center for Regional Environmental Research. The terrestrial model was developed at the Center for Environmental Risk Research. We aimed to simulate the multimedia fate of radioactive substances by coupling the three models using appropriate geographic resolutions. The major achievements of the terrestrial and the oceanic simulations are described in Chapter 9.2 and 9.3, respectively, and the major achievements of the atmospheric simulation are described in Chapter 10.3.

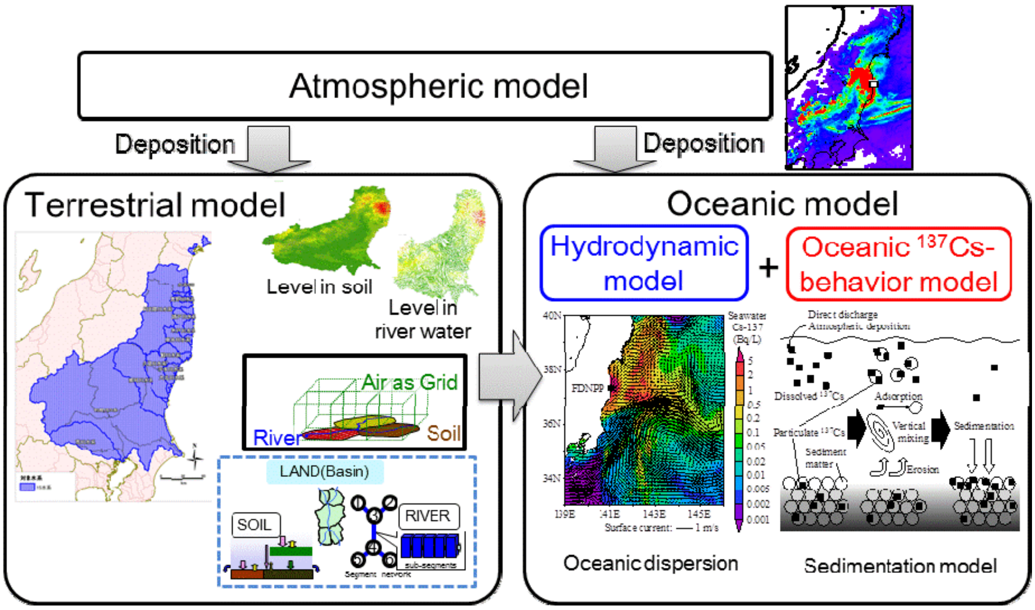


Fig.9.1 Schematic of the three models for simulating the fate of ^{137}Cs in and around Fukushima Prefecture.

9.2 Terrestrial environment

We have developed a model for predicting the long-term fate of terrestrial r-Cs in the polluted areas, and it involves modeling the processes involved in determining the long-term fate of r-Cs. The model is based on the "Grid-Catchment Integrated Environmental Modeling System (G-CIEMS)", which was originally developed for assessing the risks posed by organic pollutants. The model components and environmental conditions that were used in our model were based on the default dataset used in G-CIEMS. However, we revised several of the environmental conditions related to the fate of ^{137}Cs using the results of observations and conditions that have been used in published reports. We used the physicochemical properties of ^{137}Cs from previous reports, and ^{137}Cs deposition input data from a simulation performed using our atmospheric model. The results of our atmospheric model and airborne monitoring surveys have shown that a large proportion of the terrestrial environment that was heavily polluted with ^{137}Cs was mountainous forest. We also found that in forest areas, r-Cs was predominantly attached to particles and moved with the surface runoff (see Chapter 5 for more details).

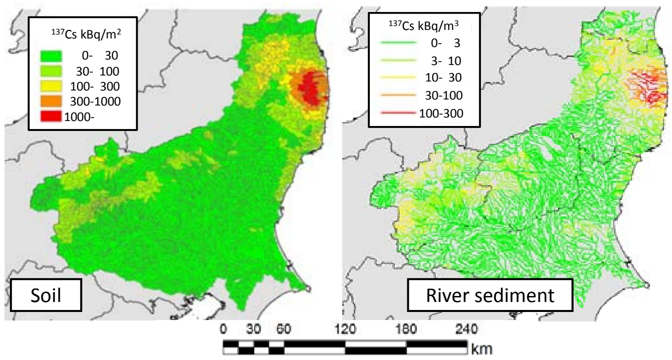


Fig. 9.2 Simulated ^{137}Cs concentrations in soil (on 31 March 2011) and river sediment (on 31 March 2014).

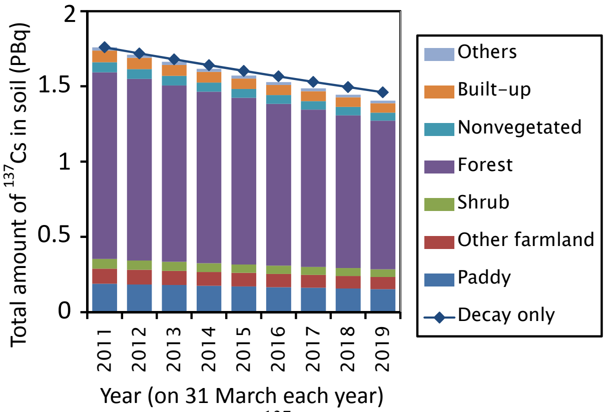


Fig. 9.3 Long-term ^{137}Cs concentration trend in soil with respect to land use.

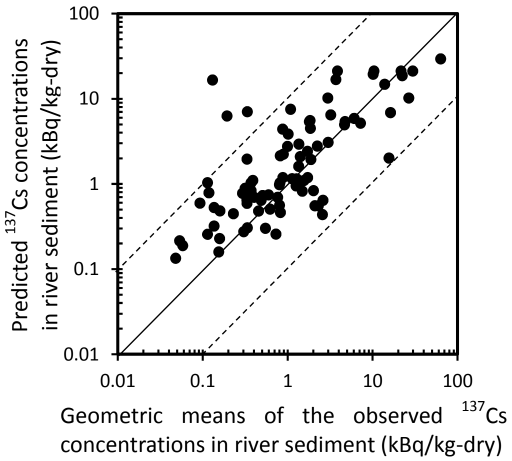


Fig. 9.4 Relationship between the observed and simulated ^{137}Cs concentrations in river sediment

The terrestrial area used in the simulation was about 3.4×10^4 km^2 in area and consisted of 3,532 unit river basin segments, each with varying proportions of seven land uses. The simulation was performed from soon after the FDNPP accident until 2019, and the annual mean amounts of ^{137}Cs remaining in the land, surface water, and sediment in surface water bodies were predicted. Examples of the simulation results are shown in Figs. 9.2 and 9.3. We found that 70% of the total amount of ^{137}Cs that was deposited on the land surface was deposited in forested areas. The rate at which the amount of ^{137}Cs remaining on the land surface was found to decrease was slightly higher than the rate of radioactive decay (Fig. 9.3). We found that the simulated and observed mean ^{137}Cs concentrations in river sediments in Fukushima Prefecture agreed (Fig. 9.4).

To provide more accurate predictions, we will improve our model by incorporating the effects of different species of forest trees and spatiotemporal variations in precipitation and river flow rates on the behavior of ^{137}Cs.

9.3 Oceanic environment

Substantial amounts of anthropogenic ^{137}Cs caused extensive pollution of the oceanic environment off the Pacific side of east Japan when the FDNPP accident occurred. The objective of our ocean modeling study was to evaluate and predict the behavior of ^{137}Cs in the ocean and the impacts the ^{137}Cs that entered the ocean after the accident will have on the marine ecosystem on the coastal shelf. We developed a comprehensive numerical model of the behavior of ^{137}Cs in the ocean, focusing on the ^{137}Cs dynamics, including advection–diffusion transport caused by water currents, adsorption and desorption to and from particulate matter, and sedimentation and suspension, including the effect of the vertical sediment activity profile. The model was found to be valid because we found reasonable agreement between the simulated and observed variations in the spatiotemporal ^{137}Cs activities in seawater and sediment in the offshore region between March and December 2011.

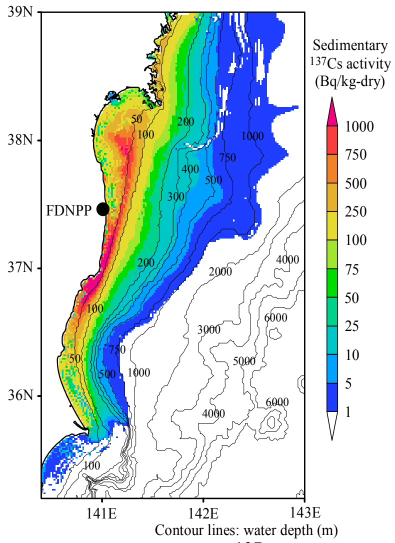


Fig. 9.5 Simulated ^{137}Cs activity distribution in surface sediment at the end of 2011.

The model was used to elucidate the mechanism controlling the spatially heterogeneous ^{137}Cs distribution in sediment in and around the shelf off the coast of Fukushima Prefecture and the adjacent prefectures. The model was able to reproduce one of the most remarkable features in the observed ^{137}Cs distribution in the sediment: a swath of notably high ^{137}Cs concentrations in sediment just offshore of the shelf (along the 50–100 m isobath) (Fig. 9.5). We concluded that the shape of the swath was closely related to spatiotemporal variations between the shear stress at the bottom of the shallow shelf

(<50 m deep) and the shear stress at the outside of the shelf. The simulated ^{137}Cs activities at the surface of the sediment on the shallow shelf were essentially consistent with the decreasing long-term trend that was observed after the ^{137}Cs was initially deposited. This would have been because strong bottom friction, leading to the disturbance of sediment, would have occurred steadily and periodically because of the spring tide that occurs about every 2 weeks and occasionally and momentarily but strongly when strong winds occurred. We confirmed that neither spring tides nor strong winds caused strong bottom friction to erode the sediment in the deeper offshore region. We therefore concluded that particulate matter containing ^{137}Cs that was horizontally transported from the shallow shelf tended to accumulate and remain on the sediment surface just offshore of the shelf edge.

The simulation also showed that the bottom disturbance influenced the ^{137}Cs distribution in the sediment vertically as well as horizontally. The ^{137}Cs concentration in the sediment from deeper (>10 cm) into the seabed was considerably higher than the ^{137}Cs concentration in the upper part of the seabed in the shallow shelf region, especially near the shore by the nuclear power plant, at the end of 2011. The calculated total ^{137}Cs concentration in the sediment over the entire simulated region (1.4×10^5 km^2) was found to be 3.2 PBq, more than 10 times higher than previous estimates based on the analysis of ^{137}Cs activities in upper sediment samples.

The ocean modeling study will be extended in the near future (by the end of 2015) so that the long-term behavior of ^{137}Cs in sediment can be predicted, taking into consideration the migration of ^{137}Cs in the marine ecosystem and the discharge of ^{137}Cs from river basins.

10. Measurements and modeling of radionuclides from the Fukushima Daiichi nuclear power plant in the atmosphere

10.1 Introduction

Observational and modeling approaches are both necessary to allow the atmospheric behaviors and impacts of radionuclides to be understood. We measured and modeled the concentrations of radioactive materials in the atmosphere immediately after the nuclear accident at the FDNPP occurred in March 2011, and as described below, our data will contribute to understanding of the atmospheric behaviors of radioactive materials.

10.2 Characteristics of the accident-derived radionuclides observed at Tsukuba

We started monitoring radionuclides in surface air at Tsukuba (about 170 km from the FDNPP) soon after the accident, on 15 March 2011 (Doi et al., 2013). The main radionuclides that we observed were radioiodine (^{131}I, ^{132}I, and ^{133}I) and radiocesium (^{134}Cs, ^{136}Cs, and ^{137}Cs). The temporal variations that were found in the particulate ^{131}I activity as a percentage of the total ^{131}I activity in the surface air are shown in Fig. 10.1. The particulate ^{131}I activity ranged from 0% to 86% of the total ^{131}I activity, and increased when the major emission plumes from the power plant arrived. This suggests that more particulate ^{131}I than gaseous ^{131}I was emitted into the atmosphere when the emission rate was high. The median aerodynamic diameter of the ^{131}I activity that was observed in April 2011 was 0.7 μm for particles bearing radioiodine and >1 μm for particles bearing radiocesium.

The long-lived nuclide ^{129}I can be detected by accelerator mass spectrometry even when the short-lived nuclide ^{131}I has decayed (Xu et al., 2015). Water-soluble and alkaline (NaOH) leachable I− contributed 42–61% and 32–44%, respectively, of the total ^{129}I found in the aerosols collected at Tsukuba in March 2011 (Fig. 10.2). However, almost all of the stable ^{127}I was water-soluble. Water-soluble IO_3^- contributed less than 0.5% of the total ^{129}I concentration. The NaOH leachable iodine was associated with organic matter. The iodine in the residues could have been associated with oxides or minerals. The large inorganic ^{129}I fraction could be attributed to $^{129}I_2$, the main form of ^{129}I released from the damaged nuclear reactor. The large proportion of ^{129}I in the NaOH leachable fraction could be attributed to $^{129}I_2$, which is highly reactive with organic particles released by vegetation. The NaOH-soluble fraction of radiocesium contributed 53–91% of the total radiocesium, and the water-soluble fraction contributed less than 15% (Fig. 10.2). It has been reported that sulfate aerosols are the main carriers of radionuclides, but our results clearly contradict this. Organic substances might have been the main carriers of alkaline-leachable radiocesium and radioiodine.

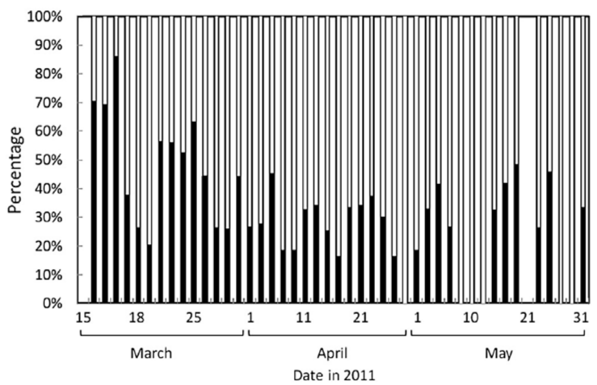


Fig. 10.1 Contributions of particulate ^{131}I (solid bars) and gaseous ^{131}I (empty bars) to the total ^{131}I concentrations found at Tsukuba between March and May 2011.

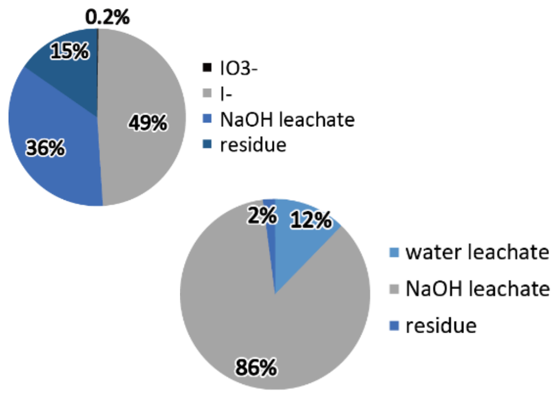


Fig. 10.2 Speciation of ^{129}I (upper) and radiocesium (lower) in the aerosol samples collected in Tsukuba in March 2011.

We are now collecting aerosol samples at 2-week intervals in Iitate village, Fukushima, to allow the internal doses caused by inhalation and resuspension caused by decontamination processes to be assessed. The estimated inhaled dose was <0.001 mSv/y at most (see Chapter 12).

10.3 Atmospheric simulation using a regional transport model

Chemical transport models played key roles in improving our understanding of the atmospheric behaviors and deposition patterns of radioactive materials emitted from the FDNPP. Immediately after the accident, we started a simulation of the behavior of radiocesium (^{137}Cs) and radioiodine (^{131}I) in the atmosphere. We simulated the atmospheric behaviors of ^{131}I and ^{137}Cs using version 3.1 of the “Weather Forecast and Research Model” and the chemical transport model “Models-3 Community Multiscale Air Quality” (Morino et al., 2011). The model roughly reproduced the observed temporal and spatial variations in the deposition rates over 15 prefectures in eastern Japan. A budget analysis indicated that approximately 13% of the ^{131}I and 22% of the ^{137}Cs had been deposited over land and that the rest was deposited over the ocean or transported out of the model domain (700 × 700 km^2). This was the first time such a regional-scale atmospheric simulation was published after the accident, so significant public concern was generated after the press release was made. The simulated data were also used to make the decisions about the countermeasures that were to be taken to address the radioactive contamination of water and land that had occurred.

We also performed sensitivity simulations to evaluate the uncertainties in the atmospheric model associated with key model settings, including the emission data and wet deposition modules (Morino et al., 2013). We found that a simulation using emissions estimated using a regional-scale (~500 km) model reproduced the observed ^{137}Cs deposition pattern in eastern Japan better than simulations using emissions estimated using local-scale (~50 km) or global-scale models. A simulation using a process-based wet deposition module reproduced the observations well, whereas a simulation using scavenging coefficients gave large uncertainties associated with the empirical parameters. The best available simulation reproduced the observed ^{137}Cs deposition rates in high-deposition areas (>10 kBq m^{-2}) within one order of magnitude (Fig. 10.3) and showed that the deposition of radiocesium over land occurred predominantly during 15–16, 20–23, and 30–31 March 2011. Atmospheric concentrations of ^{137}Cs were recently retrieved from radioactivity measurements of suspended particulate matter collected on filter tapes in suspended particulate matter monitors (Tsuruta et al., 2014). We used ^{137}Cs concentrations determined at 88 monitoring stations in the Tohoku and Kanto regions during 15-16 and 20–24 March 2011 to evaluate the performance of the model in simulating atmospheric ^{137}Cs concentrations.

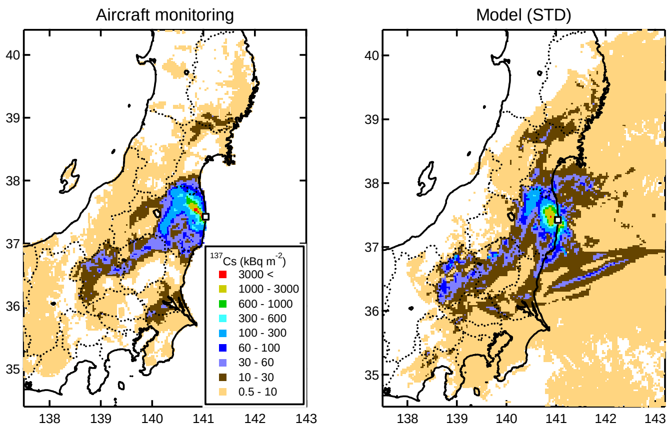


Fig. 10.3 Radiocesium (^{137}Cs) deposition maps produced from observations made from aircraft (on the left) and from a standard simulation model (on the right)

We have also participated in an international model intercomparison project that was organized by the Science Council of Japan (Science Council of Japan, 2014). Ten atmospheric regional-scale models were assessed in the project, and the conclusions were that meteorological and wet deposition simulations are important to regional-scale models, and ensemble simulations were found to be useful for simulating Cs deposition patterns.

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11. Effects of low-level gamma irradiation on wild animals and higher plants

In 2011, a considerable amount of radioactive material was released from the FDNPP, contaminating a wide surrounding area in which all the wild animals and plants remain exposed to radiation. Exposure to radiation induces accumulation of DNA mutations, which result from DNA damage such as strand breaks caused by direct ionization effects and/or indirect oxidative stress. If such adverse effects occur in germ cells, unexpected mutations may be passed to future generations through inheritance. A few studies have reported some effects on wild organisms and populations related to the low-level gamma radiation in Fukushima. However, there are no reports that demonstrate the effects of such nuclear radiation from contaminated soil within Fukushima Prefecture on organisms at the molecular level. Consequently, the two following experiments were conducted: (1) the genetic variations in wild rodents living within the forested area of Fukushima Prefecture were evaluated, and (2) transgenic plants that can detect repair of damage caused to DNA by radiation were used to evaluate the recovery from gamma-radiation-induced DNA damage. The obtained results are presented in the following.

1) The aim of this study was to assess the level of DNA damage caused by radiation to the Japanese field mouse (*Apodemus speciosus*), which is ubiquitous within the lowland forests of Japan. In 2012, mice were captured in areas showing air dose rates of 10–20 μSv/h in Fukushima Prefecture and in control areas (Aomori and Toyama prefectures). These animals were used for anatomical observations and immunostaining analysis using the 8-hydroxydeoxyguanosine (8-OHdG) antibody. The 8-OHdG is produced by the oxidization of deoxyguanosine (dG: a component of DNA) and its accumulation rarely induces a single-base substitution of DNA. The immunostaining analysis of testes showed that the appearance ratio of 8-OHdG-positive cells in seminiferous tubules was relatively high in *A. speciosus* from Fukushima compared with the control areas (Fig. 11.1). This suggests that the DNA mutation of sperm in animals from Fukushima Prefecture is higher than in other places. To test this assertion, we compared the genetic variations between wild mice populations from Fukushima, Aomori, and Toyama prefectures. Sequence analyses of the regulation region (D-loop) or cytochrome b region (Cytb) in mitochondria were performed. In addition, we undertook a comparison of the average gene diversity using microsatellite markers. Genomic DNA was isolated from the livers of the mice and used for amplification of the D-loop or Cytb via the polymerase chain reaction (PCR). Nucleotide sequences of PCR products were determined by direct sequencing and the obtained DNA sequences were compared. The results showed no significant differences between the D-loop and Cytb nucleotide sequence diversity in the wild mice from Fukushima, Aomori, and Toyama prefectures. We used eight microsatellite markers, which also showed the absence of any significant difference in the average gene diversity between the wild mice captured in different areas (Fig. 11.2). These findings indicate that the present radiation level increases oxidative stress in testes, but that it might not affect the mutation rate of mitochondrial DNA and microsatellite loci.

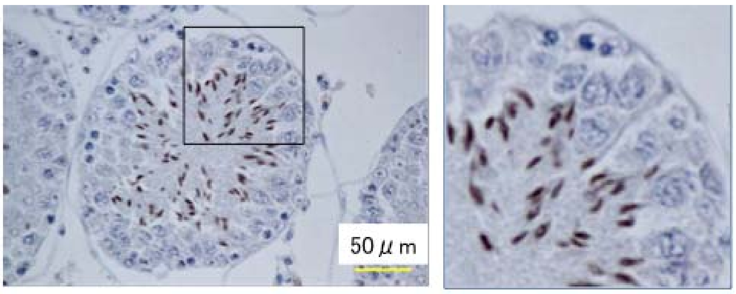


Fig. 11.1 Immunostaining 8-OHdG in sperm cells of wild rodents. Left; a tubuli seminiferi stained by 8-OHdG antibody. Right; higher magnification of the square region in left-hand photo. Cells that have oxidized DNA are stained brown.

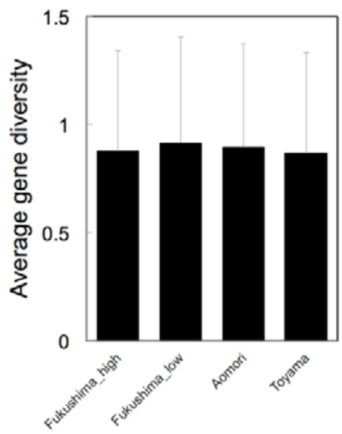


Fig. 11.2 Average gene diversity of *Apodemus speciosus* using eight microsatellite markers in each study site. The values are expressed as the mean ± standard deviation.

2) To evaluate the DNA repair that followed the gamma-irradiation-induced DNA damage from the contaminated soil in Fukushima Prefecture, we established transgenic plants for biomonitoring. We used a gene encoding beta-glucuronidase (GUS) that can metabolize the X-Gluc to 5, 5′- dibromo-4, 4′-dichloro-indigo. The accumulation of 5, 5′- dibromo-4, 4′-dichloro-indigo in cells can be detected with the naked eye as a blue–green color. Thus, we used the GUS gene as a reporter gene to detect DNA damage. Several types of DNA damage (e.g., point mutation) are known to be induced by gamma irradiation; therefore, we developed transgenic plants that can detect the repair of double-strand breaks. To develop transgenic plants for biomonitoring, a GU–US construct, in which a GUS gene is separated into two parts with 600 bp of overlapping sequences in inverted orientation, was introduced into *Arabidopsis thaliana*. This plant can detect double-strand breaks caused by gamma irradiation because the GUS activity can be restored via homologous recombination between the two repeats in the GU–US construct. Therefore, cells in which homologous recombination events have occurred because of a double-strand break can be detected by the restoration of gene activity. We developed four lines of transgenic *A. thaliana* (#651, #1406, #1411, and #1415) containing the GU–US transgene. Preliminary studies showed that the #1406 line was best for the evaluation of DNA repair, because the plants exhibited an increase of GUS-derived spots on their leaves in association with the increase of the dose of external gamma irradiation. Thus, we performed further experiments using this transgenic line. The transgenic plants were grown for 30 days on soil contaminated by different air doses collected from three sites within Fukushima Prefecture (final irradiation doses were 261, 1,340, and 2,840 μSv). Control plants were also grown on non-contaminated soil for 30 days (final irradiation dose was 57.6 μSv). Thereafter, GUS staining analysis was performed to estimate the frequency of DNA repair within the plants. Typical GUS staining patterns in plants grown on both clean and contaminated soils are shown in Fig. 11.3. The results revealed that elevated levels of gamma irradiation increased the frequency of somatic homologous recombination in a dose-dependent manner (Fig. 11.4a). As described above, GUS spots on leaves occur because of the endogenous DNA-repair system of plants. Therefore, if DNA-repair frequency is not changed in a dose-dependent manner, the accumulation of DNA mutations would be expected to occur. Our results showed that although DNA damage was induced by gamma radiation from the contaminated soil in a dose-dependent manner, an increase in DNA mutation was not detected. Furthermore, the DNA repair frequency in plants grown on the contaminated soil was no different than the plants exposed to the same external dose of gamma irradiation (Fig. 11.4b). This indicates that DNA damage caused by contaminated soil could occur mainly from external exposure to gamma radiation.

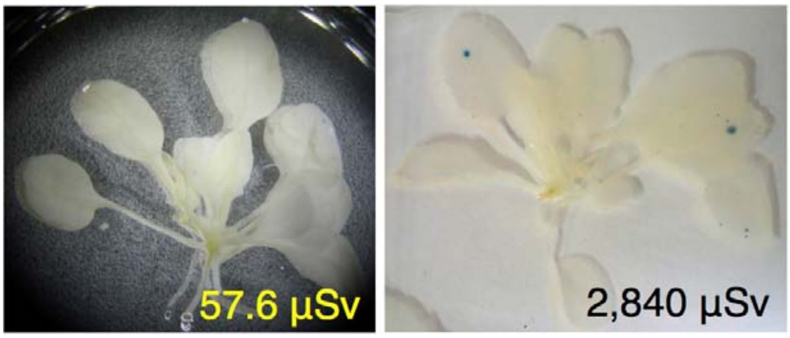


Fig. 11.3 Appearance of GUS spots in plants grown on clean (left) and contaminated (right) soil. Integrated values of radiation are shown at bottom of each photo. GUS-derived spots appear as blue–green color on leaves.

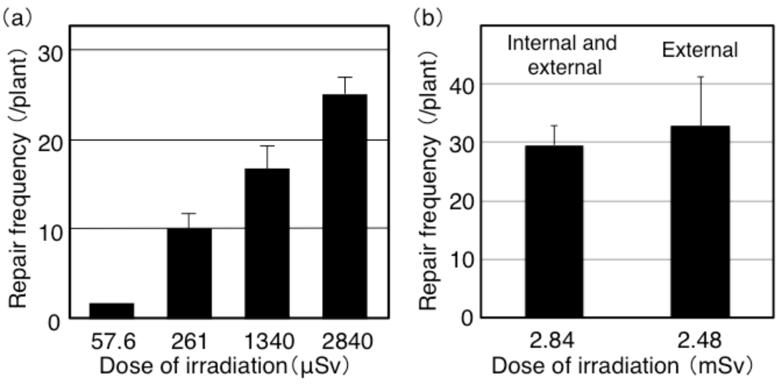


Fig. 11.4 (a) DNA-repair frequency in plants grown on soils contaminated with different levels of radioactive Cs. Values are means ± standard deviations.
(b) Comparison of DNA-repair frequency in plants grown on contaminated soil (left) or under gamma ray irradiation (right). The values are expressed as means ± standard deviations.

12. Long-term dose estimation using ambient monitoring and an exposure model

To estimate a radiation dose derived from the FDNPP accident and a major route of radiation sources, we used a combination of environmental measurements and a numerical exposure model.

12.1 Monitoring

We measured r-Cs concentrations in air, soil, indoor dust, and total diet collected in Iitate, Fukushima Prefecture, as well as in an area where we had observed relatively high radiation levels (i.e., a "hotspot"), and calculated the radiation exposure from each source. Summary: additional work including detailed indoor environmental measurements and evaluations of the sources of indoor radiation are warranted to reduce the possible level of dose to those who return to the contaminated areas in the future.

12.1.1 Case study in Kashiwa (hotspot in Kanto region)

The estimated annual doses (January 2012 to December 2012) of five people were 0.29–0.74 mSv/year and 90%–99% of the doses were from external exposure. The person exposed to a dose of 0.29 mSv/year was working in Tokyo (less contaminated). These results were used to validate the exposure model.

12.1.2 Ambient air and indoor dust samples were continuously collected and analyzed for r-Cs.

The amount of r-Cs in indoor dust collected in Tsukuba is shown in Fig. 12.1. The concentration of r-Cs has gradually decreased from soon after the accident to the present-day level; however, concentrations of several hundred Bq/kg of r-Cs were detected even four years after the accident. The majority of the ambient air samples from two sites in Iitate from March 2012 to present did not exceed 0.001 Bq/m^3, which means the estimated inhalation dose was <0.001 mSv/year (see Chapter 10).

12.1.3 Source characterization of r-Cs in indoor dust

Up to 68% of r-Cs in indoor dust was water soluble (Fig. 12.2). In contrast, the solubility of r-Cs in soil particles was quite low. This suggests that not all the r-Cs in the dust was derived from tracked-in soil particles.

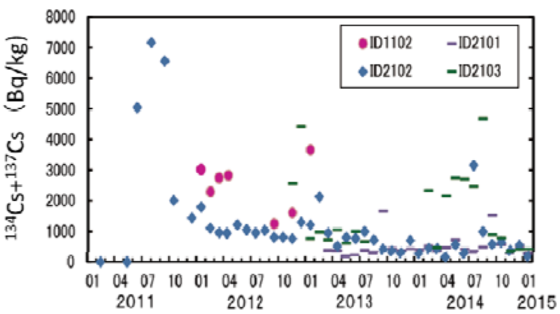


Fig. 12.1 Radioactive Cs in indoor dust.

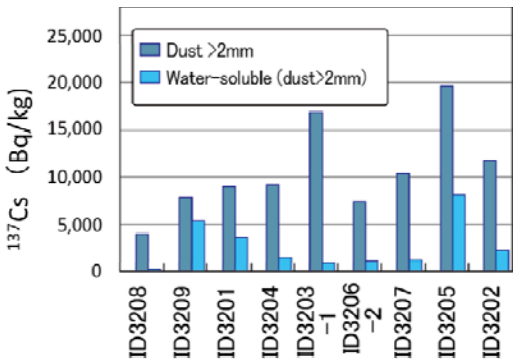


Fig. 12.2 Radioactive Cs in indoor dust by size and water-solubility fraction.

12.2 Modelling

We developed numerical exposure models for both external and internal exposures to estimate the radiation doses of general residents in eastern Japan. Diet, indoor air, indoor dust, outdoor air, and soil were considered as sources of internal radiation doses. The models were built using a set of data that we collected as well as datasets provided by other institutions. The 50th percentile of the modeled external radiation doses for the first year following the FDNPP accident for 1–6-year-old children is expressed in map format in Fig. 12.3. The predominant radiation source was external exposure (Fig. 12.4). The model output agreed reasonably well with the personal monitoring data collected at Kashiwa, while most of the model estimations for the cities in Fukushima Prefecture were overestimated. Estimation of the median dietary intake was 0.1 mSv/year; however, this estimation was much higher than that of the total diet and market basket studies. The major non-dietary source of internal radiation dose was indoor dust, followed by soil, indoor air, and outdoor air. Uncertainties and limitations of this model estimation arose from the lack of monitoring data of soil deposition, accurate behavioral data, food measurement data, information about food consumption changes after the accident, consideration about land use bias, consideration about decontamination, and consideration about the shield effects of snow and soil.

We will refine the model using information about decontamination, land use, and the shielding factor of snow and soil.

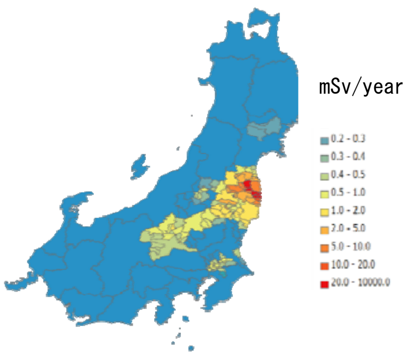


Fig. 12.3 Modeled median external exposure dose (1–6-year-olds).

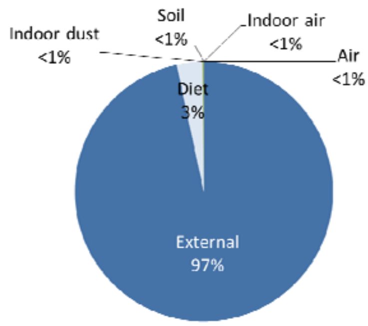


Fig. 12.4 Source of exposure to r-Cs. (One of the cities in Fukushima Prefecture. Median base)

13. Outline of the "Shinchi Life Assist Tab System" development process

13.1 Rough outline of the development of the Shinchi Life Assist Tab System

Shinchi Town in Fukushima Prefecture was designated as a "Future City" by Japan's Cabinet Office in 2011. A program was subsequently implemented aimed at creating a "Smart Hybrid Town" based on environmental, economical, and social values associated with a Future City. We collaborated closely with Shinchi Town to develop the "Shinchi Life Assist Tab System" that includes two facilitating functions: "Regional energy assist" and "Life assist" (Fig. 13.1).

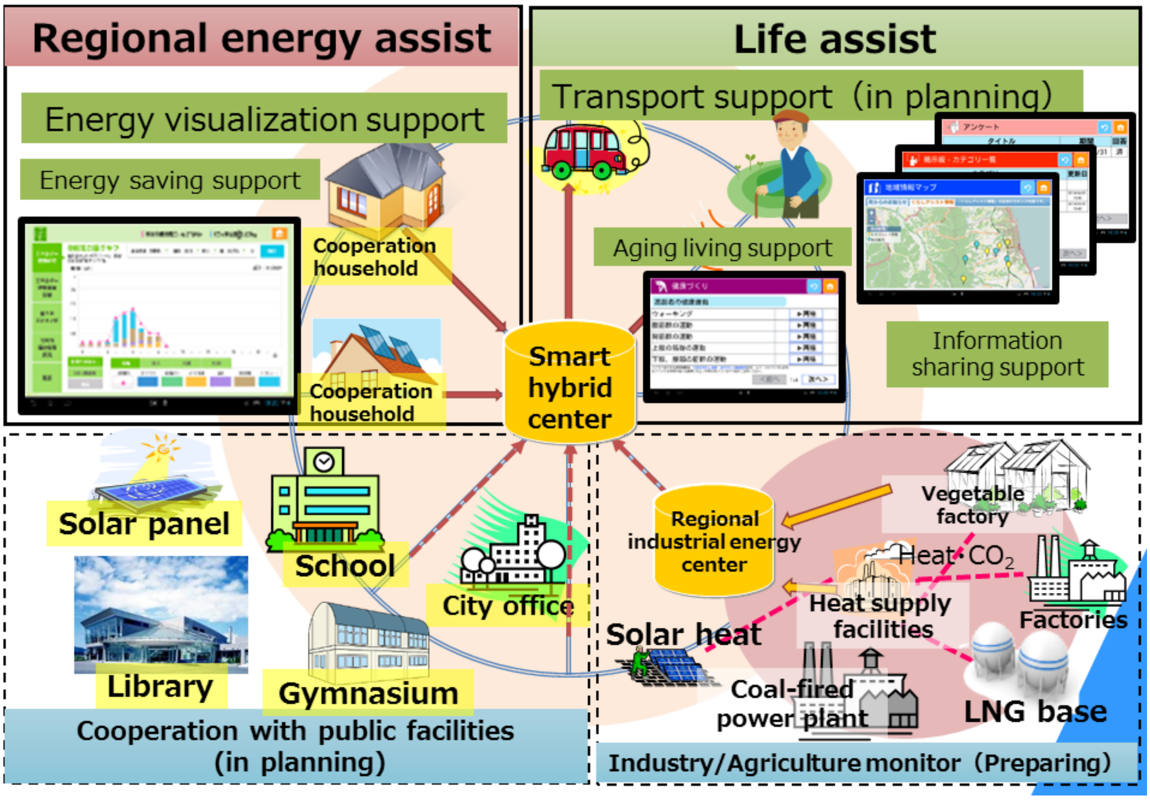


Fig. 13.1 Overview of the Shinchi life assist tab system in the Smart Hybrid Town project.

We programmed tablet computers to graphically depict energy consumption information for residential houses and public facilities, and established a regional ICT (Information and Communication Technology) system to share information regarding town development for the reconstruction process. This system also included information sharing on social and community activities such as health, welfare, and transit. In addition, we constructed a central management server system termed a "Smart Hybrid Center," and created interactive regional ICT infrastructure that was combined with the Shinchi Life Assist Tab. Regional stakeholders associated with the reconstructing municipality (e.g., residents, town officers, NPOs (Nonprofit Organizations), and local companies) were thus able to share information regarding multiple services related to eco-friendly action, welfare activity, economic activity, and transit information through the introduction of this system. We analyzed regional data compiled at the Smart Hybrid Center, and made a substantive contribution to town development activities of the reconstructing municipality. Our main objectives were as follows: (1) to promote eco-friendly action through the use of regional information, (2) to streamline the use of regional on-demand transit, (3) to support reconstruction efforts of victims of the earthquake, and (4) to share information interactively among regional stakeholders.

In 2014, we developed the concept underlying this system and implemented its basic functions. Because the regional energy assist function is one of the core components of the system, we considered concrete measures for promoting the energy saving motivation of residents. We also gave detailed consideration to the future course of technical development of this system. Consequently, we developed seven basic functions: energy, a regional information map, a bulletin board, health information, disaster information, a questionnaire, and administrative information. These functions were implemented as tablet computer applications and the system was launched in the homes of pilot users. A total of 50 households were selected as pilot users and participated in the demonstration experiment.

13.2 Experiment to conserve electricity through an energy saving campaign

To promote energy conservation activities among residents, we conducted some experiments in the form of campaigns. The campaign duration was 2 weeks, and an average of 1 week's electricity consumption before the campaign was set as the baseline. During the campaign period, daily electricity consumption was compared with the baseline, and the daily power saving rate was calculated for each result. After the campaign, the average power saving rate and ranking of each household were calculated. Special gift certificates that could be used at local shops were provided by the Shinchi local government and these were awarded to the top four households. We conducted campaigns in September and November in 2014, and March in 2015, and the maximum average power saving rate was 7% of the September rate.

In parallel, we carried out several questionnaire surveys and interviews. For these investigations, we surveyed respondents regarding their views on an eco-friendly lifestyle. Consequently, we will analyze behavior changes by combining the results of the experiments and surveys and identify the factors that determine eco-friendly actions for each household.

We will also attempt to combine the regional energy assist and life assist functions, and to develop a method for creating a low carbon community.

14. Development of recovery scenarios toward 2050 using integrated assessment models

Since the occurrence of Japan's tsunami disaster on March 11, 2011, the cities and towns in the affected region have made considerable progress toward recovery. Among the concerned municipalities, Shinchi Town aims to establish energy systems in the industries and residentials that are more energy efficient and maximum usage of local energy resources by adopting a smart network concept. The town is a relatively small municipality with a population of around 8,000. A total of 20% of the town's area was completely destroyed and approximately 500 out of 2,500 households lost their homes as a result of the disaster. Reconstruction of the infrastructure and buildings is ongoing and will require several years for completion. In this reconstruction effort, in addition to establishing new energy system, the town's government also aims to curb the trend of population decrease which emerged before the disaster, mainly through the provision of more employment opportunities and lower living costs.

Against this background, we developed a quantitative methodology for designing a comprehensive plan with consideration of a rise of population and employment, vitalization of industries, efficient use of energy with innovative technologies. The methodology consists of two integrated models. The first was a Snapshot Model for describing whole activities of the town in a consistent manner. The model covers the industrial sectors and the residential and commercial sectors, and includes transportation sectors through the commuting structure within and between regions. The second is an Endues model for focusing energy systems, including the energy efficiency of end-users, and local energy supplies such as solar PVs and cogenerations.

Figure 14.1 depicts the structure of the Snapshot model, which is designed suitable for small areas with a relatively open economic structure. In such an economy, population is strongly affected by employment opportunities and the commuting structure connecting surrounding areas. Policy issues are included as sets of parameters.

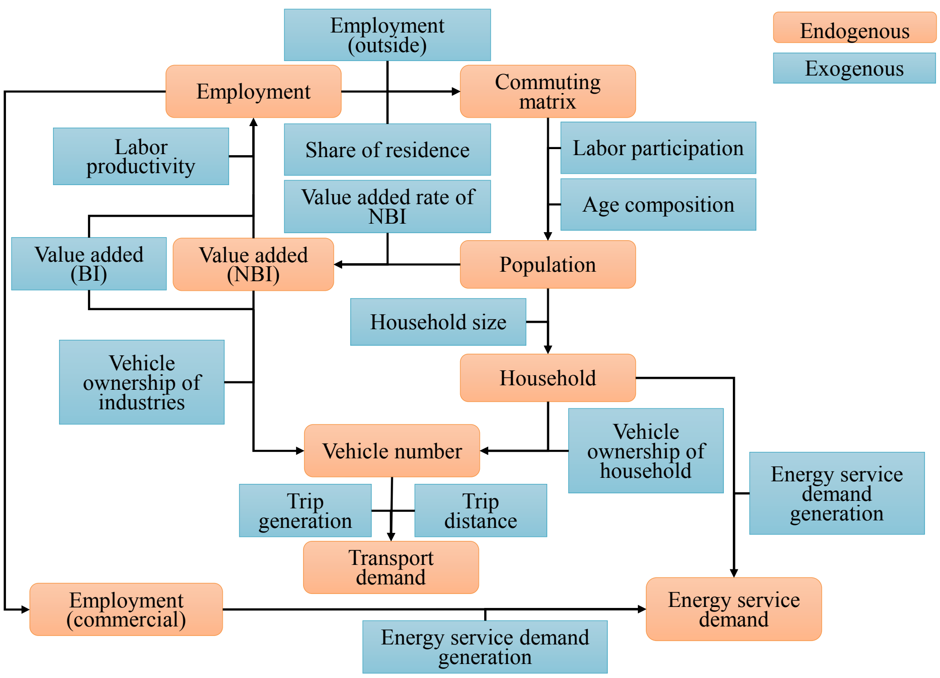
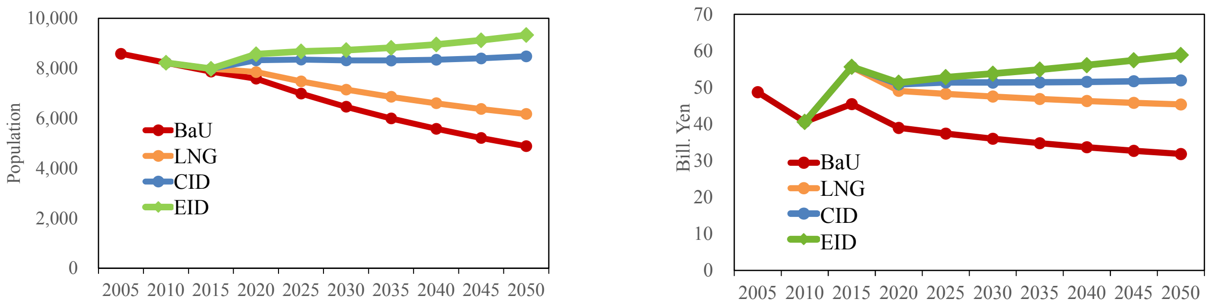


Fig. 14.1 Structure of the Snapshot model for Shinchi Town

Four scenarios have been developed for the Shinchi Town. The first was a business as usual (BAU) scenario with a continuation of the trend that prevailed before the disaster. The second was a LNG tank built scenario in which the LNG import facility (currently under construction) and related industries would operate in the town. The third is industrial development scenario (CID) which conventional manufacturing will be shifted in the town. The last scenario entailed eco-industrial development (EID), which industries for contributing industrial symbiosis will be located. The results of the scenarios for population and GDP are shown in Fig. 14.2. In the BAU scenario, the population would keep decline to about 5,000 in 2050. The GDP "spike" in 2015 has been caused by the high construction activities related to recovery from the tsunami (in all scenarios) and construction of the LNG import facility (in three scenarios except for BaU). In the BAU and LNG scenarios, after 2020, with the completing recovering activities from the disaster, GDP and population would decline over time. The population would be sustained within the CID scenario because of increased employment opportunities by newly located industries. The EID scenario entails provision of increased employment compared with CID, resulting in the population's recovery to pre-disaster levels. These results suggest that only attracting conventional manufacturing industries might not enough for maintaining the population and employment levels as current levels.

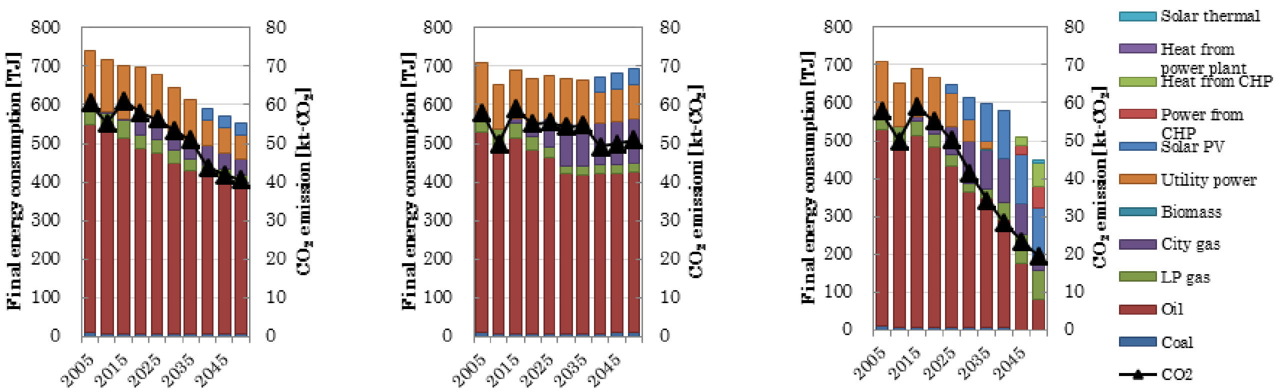


(a) LNG-BL (b) EIS-BL

Fig. 14.2 Results for population and GDP in the four scenarios

The Enduse model could analyze system configuration of energy technology in order to satisfy energy demands (e.g., heating and hot water demands) while minimizing total system costs within the given time period. Future energy service demands has been set based on activity levels derived from socio-economic scenarios. In the analysis, two of the above described socioeconomic scenarios have been employed: the LNG and EID scenarios. Two additional cases for CO_2 emissions were set up for the respective scenarios: no target case (BL) and the reduction case (EC), in which CO_2 emission in 2050 is reduced by 70% compared with 2005 levels.

Figure 14.3 shows the estimated final energy consumption and CO_2 emission in Shinchi Town for each scenario. In the LNG-BL scenario, CO_2 emission would decrease to 40 kt-CO_2 in 2050, while population and energy demands would also decrease. In the EIS-BL scenario, CO_2 emission would remain at around 50 kt-CO_2/y because of the increasing energy demand caused by population and economic growth. In the EIS-EC scenario, CO_2 emission would decrease to 10 kt-CO_2 in 2050 through the installation of solar photovoltaics (PV) and combined heat and power (CHP) plants. From these analyses, the Shinchi Town could balance regional economic development and low carbonization.



(a) LNG-BL (b) EIS-BL (c) EIS-EC

Fig. 14.3 Final energy consumption and CO_2 emission for each scenario

15. Urban revitalization planning support system based on regional energy characteristics

From the perspective of the efficient use of limited resources and energy, much attention has focused on the distributed regional energy system. This enables efficient use of both electricity and heat by facilitating practical application of regional resources that takes advantage of the proximity between supply and demand. Compared with a large-scale centralized system, the planning and operation of a region-specific system, based on the conditions of a district, assume importance within a distributed system.

This study was aimed at developing a framework to support the design of a properly distributed energy system corresponding to the characteristics of local energy supply and demand. This basic framework included three steps (Fig. 15.1). First, the energy supply conditions for an object area and the potential amount of regional energy sources were analyzed. Second, possible variations in energy demands, including electricity, cooling, heating, and hot water were estimated based on scenarios relating to land use strategies. Last, a mathematical programming model was developed for optimizing the sharing and operation of alternative energy technologies. Here, we specifically discuss the introduction of a co-generation system and its optimal design method, considering performance and installation and maintenance costs of the energy system. The objective function selected was to minimize total costs, including fuel consumption, infrastructure construction, and maintenance.

As a case study of a municipality involved in a revitalization project, we applied the model to Shinchi town in Fukushima Prefecture where a redevelopment project was currently underway around the station area (Fig. 15.2). We set up three cases to simulate different supply schemes to zones 1 and 2 (shown below), to estimate the hourly variable load in winter, summer, and the intermediate season, and to select optimum generation technologies, including heating and cooling tanks (Fig. 15.3).

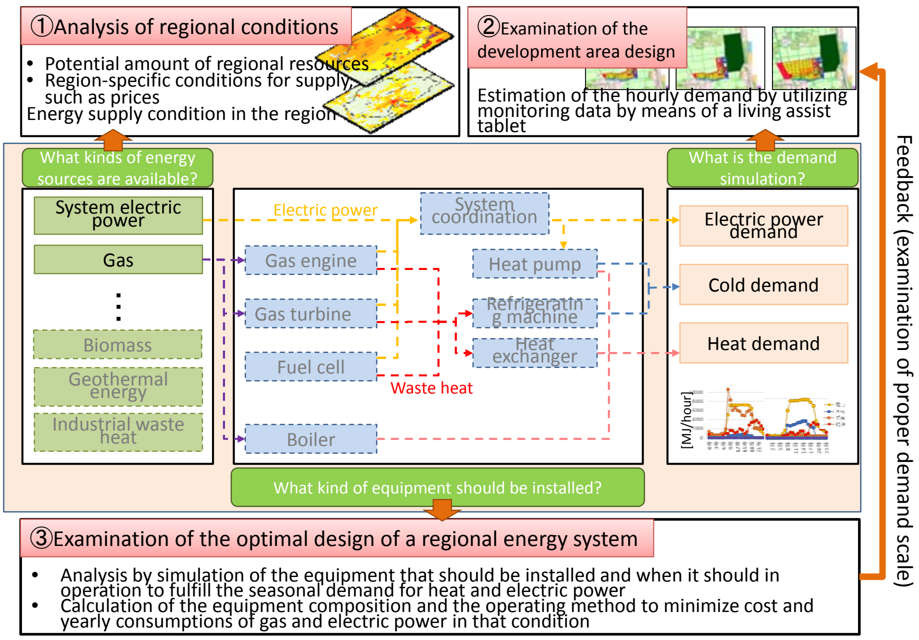
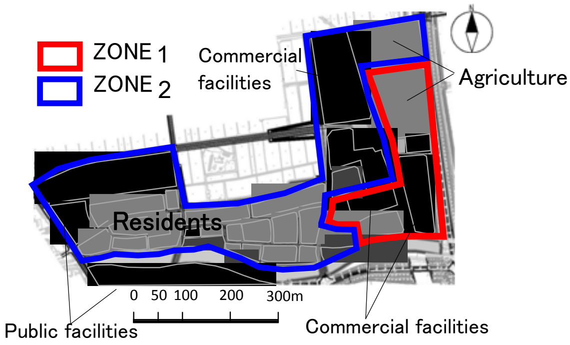


Fig. 15.1 Basic concept for the design of a distributed energy system

The optimization model returned an optimal introduction volume and operation schedule for each generation and storage technology. The capital investment cost was about 160 million yen in Case 1 and about 380 million yen in Case 2, with no purchase of power from an external supplier. In addition, a reduction in carbon dioxide emission of about 20% was expected compared with Case 0. Based on these results, we further discuss related energy policies and possible improvements to the system in terms of economic feasibility. These include subsidies for eco-businesses provided by the Ministry of the Environment and labor costs reduction through the integration of management divisions. In particular, we devised a pricing scheme for maintaining the business incomes and expenditure of the project and conducted a sensitivity analysis for each stakeholder. In addition, we examined an expanded case in which land use was induced and demand density was enhanced for increasing the efficiency of the distributed energy system. Both of these areas of knowledge are pertinent to discussions related to the design of distributed energy systems.



	Zone 1	Zone 2
Case 0	Existing system	Existing system
Case 1	Regional system	Existing system
Case 2	Regional system	Regional system

.

Fig. 15.2 Overview of the subject district for the case study and design.

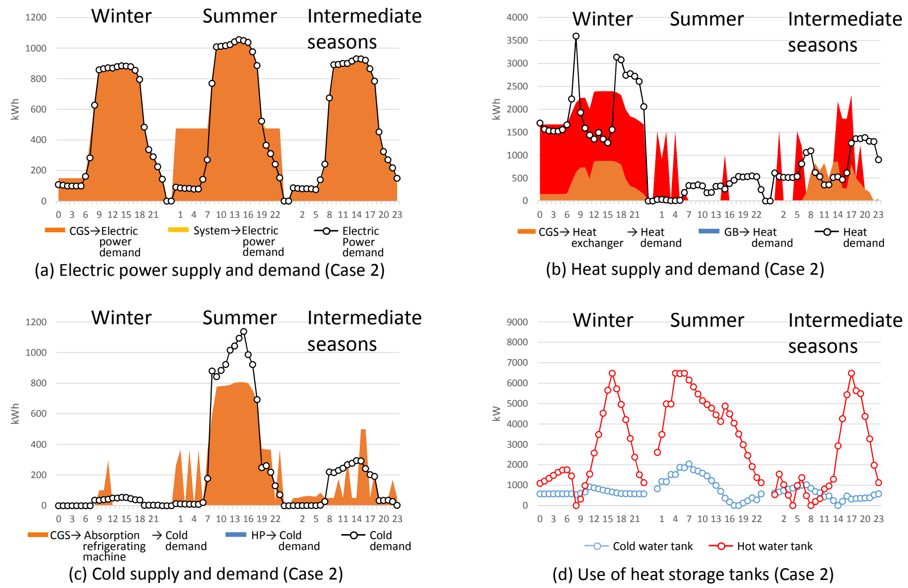


Fig. 15.3 Optimal simulation result (Case 2).

In the medium- to long-term, considering the urban development project around railway station of Shinchi Station as a core project, one of the available options is to expand the project to encompass the overall planning of the entire town, including the industrial park. Figure 15.4 depicts an image of a case scenario. In addition to strategizing the location of industries (e.g., food-related industries and data centers) that can efficiently utilize the boil-off gas and cooling energy obtained from the LNG base, it is expected that a wider-scale heat supply system will be realized compared with existing overseas cases that utilize industrial waste heat. Because thermal energy will decay as a result of the distance, it is important to focus on land use planning that considers spatial properties for laying out thermal pipelines. According to this perspective, we evaluated the transport limit of industrial waste heat by assessing energy costs and CO_2 emissions. The results indicated that even in the case of relatively small-scale plant factories, it was possible to transport heat energy to places located at a distance of 2 km from the source. In addition, because the infrastructure installation cost is an important factor that determines the transportable distance, appropriate spatial planning is a significant factor in achieving the cascading use of heat from high to low temperatures in the following order: industrial, civil, and agricultural sectors. Therefore, achieving comfortable and efficient urban development, while realizing a low-carbon and low-cost energy system that attempts to stabilize regional employment by attracting related industries, including plant factories, has become an important factor for supporting a city's revitalization.

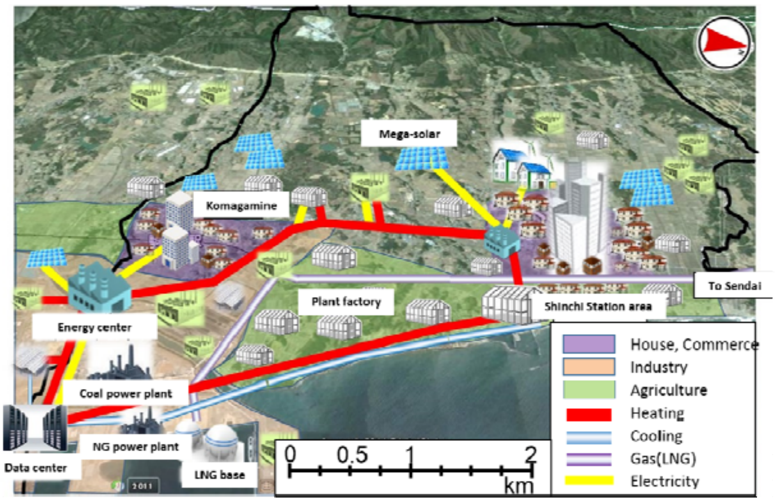


Fig. 15.4 Illustration of urban revitalization planning utilizing regional energy.

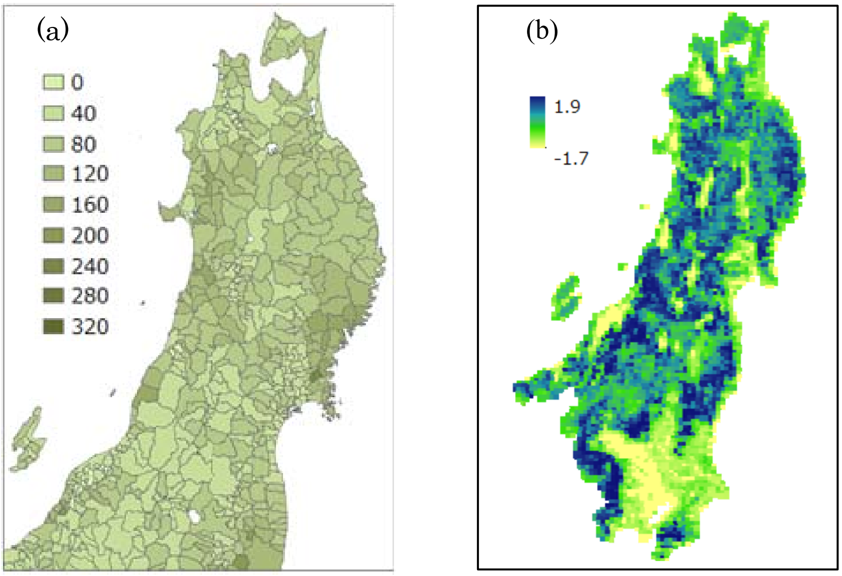


Fig. 15.5 (a). Timber accumulation in plantation forests (m^3 ha^{-1}); (b) Supporting services proxied by carbon sequestration (Mg-C ha^{-1} y^{-1}).

The feed-in tariff scheme for renewable energy was introduced in 2012 to promote these energy sources in Japan. Consequently, demand for biomass is now higher than it was before the great earthquake and nuclear accident of 2011. The impact of biomass production on ecosystem services was assessed in Japan's eastern region. Potential supplies of various types of biomass were mapped (Fig. 15.5) based on previous studies (Iuchi, 2003; NEDO, 2011), and proxy variables for ecosystem services were estimated and mapped within the region. These indices were analyzed using a multivariate statistical technique to specifically identify key factors relating to the use of biomass and ecosystem services. Priority areas of potential biomass energy supply and ecosystem services were indicated and used to analyze the conflicts between use of biomass and conservation of ecosystems.

[References]

Iuchi, M., 2004. Development of system that supporting use planning of biomass energy: modeling of storage database and cost of collecting. Central Research Institute of Electric Power Industry, Research Report Y03023, 1-26. (In Japanese with English Summary)

NEDO (2011), Estimation about Potential and Available Biomass. Available at: http://app1.infoc.nedo.go.jp/biomass/. (In Japanese)

16. Quantitative and qualitative disaster debris management system

16.1 Quantity of Disaster Debris Generated by the 2011 Tohoku Disaster

Following the 2011 Tohoku Disaster, the need for appropriate disposal of disaster debris as part of the recovery and reconstruction of catastrophically devastated areas affected by such an emergency situation was clearly recognized. To implement unhindered disaster debris disposal, we need to understand the status of the damaged areas and have both a quantitative and qualitative understanding of debris that can be generated by earthquakes, tsunamis, or other disaster events. We collected information related to damage and hazards and established a database on the amount of debris observed after the 2011 Tohoku Disaster. The amount of debris resulting from this disaster was correlated directly with the number of completely collapsed and damaged houses (Fig. 16.1, $r_s = 0.947$, $n = 31$, $P < 0.01$).

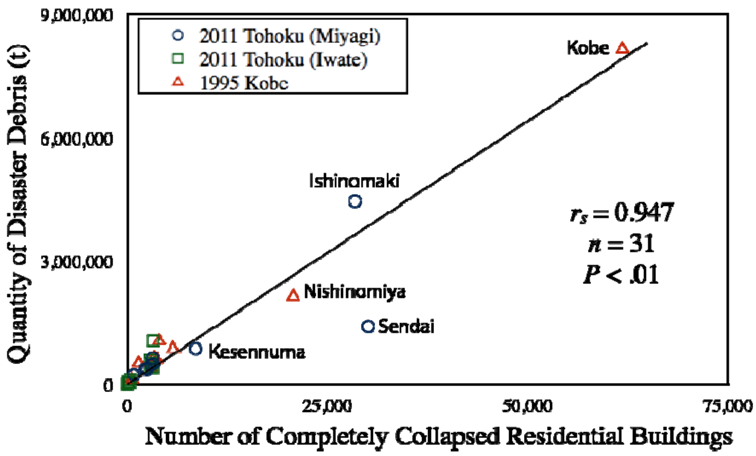


Fig. 16.1 Quantity of Disaster Debris and Number of Completely Collapsed Residential Buildings.

16.2 Estimation of Per-Unit Generation of Disaster Debris

In this study, using per-unit generation of disaster debris, including damage to housing, we estimated the discharge of disaster debris as the product of the number of damaged buildings times the per-unit generation. The purpose of this estimation was not to reveal the physical mechanism of disaster debris generation caused by natural disasters, but rather to evaluate the impact of disaster debris on the waste management system during the initial response phase of establishing disaster debris management.

We previously introduced a procedure for estimating disaster debris caused by earthquake and flood disasters during an emergency response and estimated per unit generation of disaster debris, including the extent of housing damage (Hirayama, et. al., 2010). In Japan, the Disaster Countermeasures Basic Act stipulates that responsibility for reporting the damage situation and emergency response, including the extent of damage to buildings, lies with the upper administrative levels (Society for the Study of Administrative Disaster Prevention, 2002). In the aftermath of a disaster, damage reports, including the number of residential buildings damaged should be announced by the Fire and Disaster Management Agency. According to the per unit generation, which includes housing damage, an estimation of the quantity of disaster debris is given in equation (1):

$$Q_{dd} = \sum C_i N_i , \qquad (1)$$

where the amount of disaster debris is designated by Q_{dd}. C_i represents per-unit generation of debris, including rubble from damaged housing structures, and the subscript i refers to the classification of building damage. The number of damaged residential buildings is designated by N_i.

The number of damaged residential buildings can be estimated based on the fragility function of buildings from census data such as those on population, number of houses and households, and from damage data depicted in natural hazard maps such as seismic intensity, inundation depth, and inundation areas.

We used multivariate linear regression modeling, controlling for the number of damaged dwellings to estimate the per-unit generation of disaster debris. Estimations of the per-unit generation of complete and moderate collapsed buildings, respectively, were 116.9 t/house and 23.4 t/house (R-squared = .959, F (2, 19) = 253.85 (p = .000)). Table 16.1 shows per-unit generation, including housing damage.

Table 16.1 Per-unit generation including housing damage

Housing damage	Per unit generation (t)
Inundation under flood level	0.62
Inundation	4.6
Moderate collapse	23.4
Complete collapse	116.9

16.3 Discharge of Disaster Debris for Different Categories of debris

Estimation of disaster debris discharge for each categories of debris is required for operations. In this study, the amount of each specific type of disaster debris was calculated as the proportion of the specific type of disaster debris discharge to the total amount of disaster debris. The discharge of specific types of disaster debris is given in equation (2):

$$Q_{dd(cat)} = K_{cat} Q_{dd}, \qquad (2)$$

where $Q_{dd(cat)}$ represents the quantity of specific disaster debris in each category. K_{cat} is the proportion of a specific disaster debris discharge, and the subscript *cat* refers to the categories of disaster debris.

Earthquake disaster debris generated by the 1995 Hanshin–Awaji Earthquake consisted of 72.5% construction and demolition (C&D) debris from wooden housing and 27.5% C&D debris from public structures/buildings (Hyogo Prefecture, 1997). The C&D debris from wooden housing (72.5%) consisted of the following debris types: 39.0% concrete, 19.5% wooden debris, 2.5% metals, and 39.0% mixed debris.

The C&D debris from public sections (27.5%) consisted of the following proportions of debris types: 97.2% concrete, 1.4% wooden debris, and 1.4% metals. In this study, disaster debris was classified into five categories: burnable, unburnable, concrete, wooden, and metal. K_{cat} denoted the observation results of the 2011 Tohoku disaster, as shown in Table 16.2.

Table 16.2 Proportion of disaster debris discharge in each category

Categories of disaster debris	K_{cat}
Burnable	0.18
Unburnable	0.18
Concrete	0.52
Wooden debris	0.054
Metal	0.066

16.4 Estimation Results of the Quantity of Presumed Earthquake Disasters

The Central Disaster Prevention Council examined scenarios for a catastrophic earthquake and tsunami in the Nankai Trough and for an earthquake in the Tokyo Metropolitan Area (The Central Disaster Prevention Council, 2013). In this study, ground motion and seismic intensity based on the Japanese seismic scale in the GIS system were estimated. Tsunami inundation areas and depth were also estimated. First, we used the estimated results of seismic intensities and tsunami inundation depth in each grid in the GIS system to calculate the number of damaged residential buildings. The calculation was based on fragility curves that described the correlations between seismic intensity, inundation depth, and the rate of housing damage.

Next, using per-unit generation of disaster debris, we calculated the amount of earthquake disaster debris that was projected to be generated by a catastrophic earthquake and tsunami in the Nankai Trough and by an earthquake disaster in the Tokyo Metropolitan Area. These are shown in Figs. 16.2 and 16.3. The quantity of disaster debris generated by the projected catastrophic earthquake and tsunami in the Nankai Trough was estimated at 350.0 million t. The quantity of disaster debris generated by the projected earthquake disaster in the Tokyo Metropolitan Area was estimated at 110.0 million t.

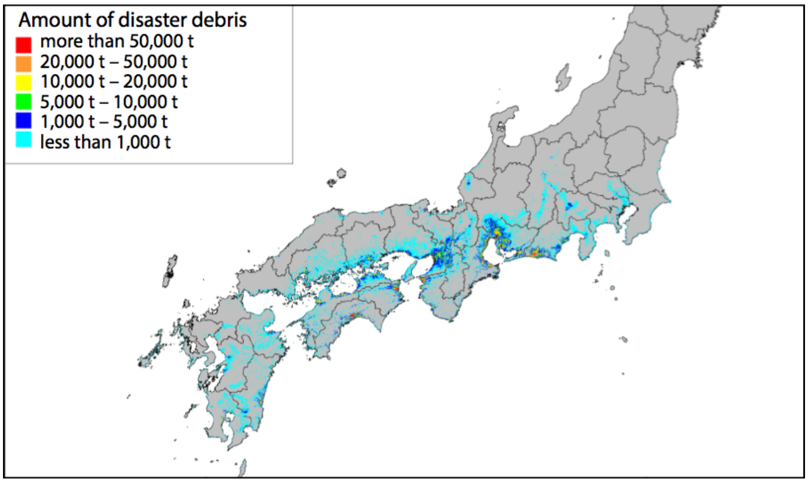


Fig.16.2 Estimation results for the amount of disaster debris generated by a projected catastrophic earthquake and tsunami in the Nankai Trough.

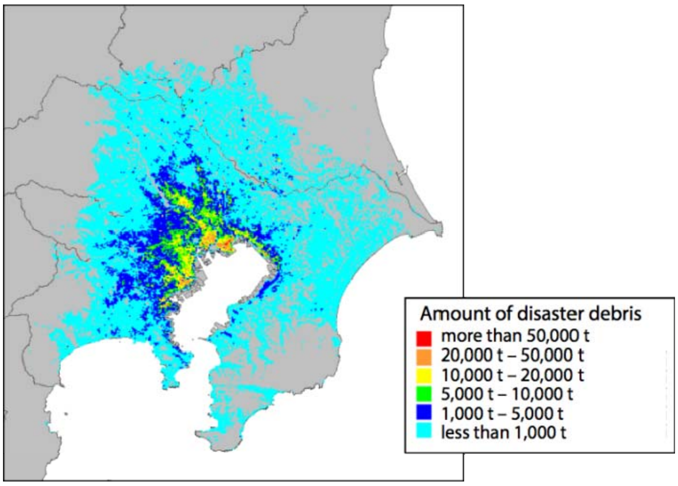


Fig. 16.3 Estimation results of the amount of disaster debris generated by a projected earthquake in the Tokyo Metropolitan Area.

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Hirayama N., Shimaoka T., Fujiwara T., Okayama T., and Kawata Y. (2010). Establishment of Disaster Debris Management Based on Quantitative Estimation Using Natural Hazard Maps. Waste Management and the Environment V, WIT Transactions on Ecology and the Environment, 40, 167-178.

Society for the Study of Administrative Disaster Prevention. (2002). Explanation Article by Article of the Disaster Countermeasures Basic Act, 264-271.

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17. The role of public management in disaster waste management: institutions, functions, and planning

In addition to engineering technology, public management is considered to play a significant role in ensuring smooth and appropriate disaster waste management (DWM) after major disasters. We examined three important aspects of public management; notably, institutions, organizational functions, and planning.

Regarding the first aspect, the impacts of institutional arrangements on DWM actions and outcomes were examined based on the framework shown in Fig. 17.1. Institutional arrangements made after the Tohoku Earthquake were first reviewed and categorized to reveal their characteristics. Subsequently, their impacts on the actual DWM process and outcome in three selected devastated municipalities were analyzed using the case study method. The results of the study showed that while some of the institutions had a direct impact on DWM operations or on the public management aspects of DWM actions, others affected DWM operations via their effect on public management. A particular finding was that partial simplification of the permission processes for waste facility installation, and of the requirements for waste disposal procedures, enhanced the progress of DWM, especially when additional simplification measures were taken by the concerned municipalities. The findings also suggested that institutional arrangements issued relatively late did not have their intended effect or, in fact, caused confusion and posed an additional administrative burden to local governments.

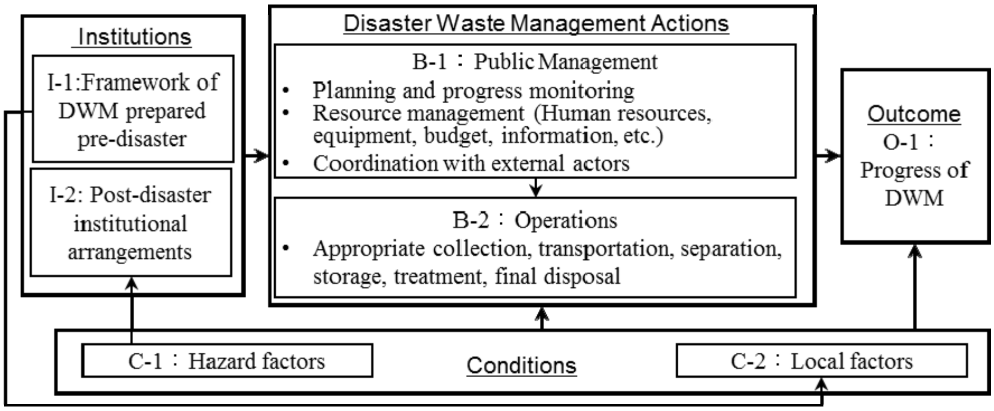

Fig. 17.1 Impact of institutions on disaster waste management(source: Tajima et al., 2014a, translated).

In addition to understanding the impacts of institutions on DWM actions and outcomes, it is also important to understand what functions are required within responsible/relevant organizations for undertaking DWM actions (tasks). Functions necessary for DWM were ascertained by structuralizing actual DWM tasks observed in the case of the Tohoku Disaster. Data collected through a series of interviews and literature surveys were structuralized using a hypothetical DWM support function framework based on the five principal emergency response functions used in the US Incident Command System (ICS). These were: operations, command, logistics, finance/administration, and planning. Our analysis showed that the hypothetical framework was well matched with actual DWM practices. Emergency support functions, namely, the five basic functions and their corresponding subfunctions for DWM were identified. These are shown in Fig. 17.2.

Six subfunctions were identified under operations that collectively represented a typical waste management process. As revealed in Fig. 17.1, this basic function corresponded to “B-2: Operations,” and the four remaining basic functions, described below, corresponded to “B-1: Public Management” which supported operations.

The command function comprised the following four basic subfunctions: (1) target setting (setting targets in terms of time boundaries and/or quality); (2) public relations (communicating information to the public, including that on disaster waste separation methods and collection schedules); (3) external affairs (coordination and negotiation with actors outside of the local government, e.g., those within the central government and private waste management companies and land owners); and (4) internal affairs (coordination with different departments, e.g., disaster management, environmental protection, and urban planning). The logistics function was related to management (procurement, distribution, and maintenance) of different types of resources (human resources, equipment, facilities, and systems). Here, the systems subfunction indicated both information systems, such as those for disaster waste quantity management and social systems (laws and regulations). The finance/administration function was also necessary, especially because local governments required external resources to complete their DWM operations. The contract subfunction, encompassing all of the administrative procedures required for subcontracting operations, the payment subfunction for the maintenance and finalization of contracts, and the financial source subfunction, which mainly indicated subsidies gained from the central government, were all important divisions of the finance/administration function. Planning was the final basic function entailing the integration of all of the different DWM functions and tasks. Gathering, sharing, and analysis of information regarding damage, waste generation, DWM progress, environmental contamination, and other pertinent issues were found to be necessary for achieving adaptive and flexible DWM.

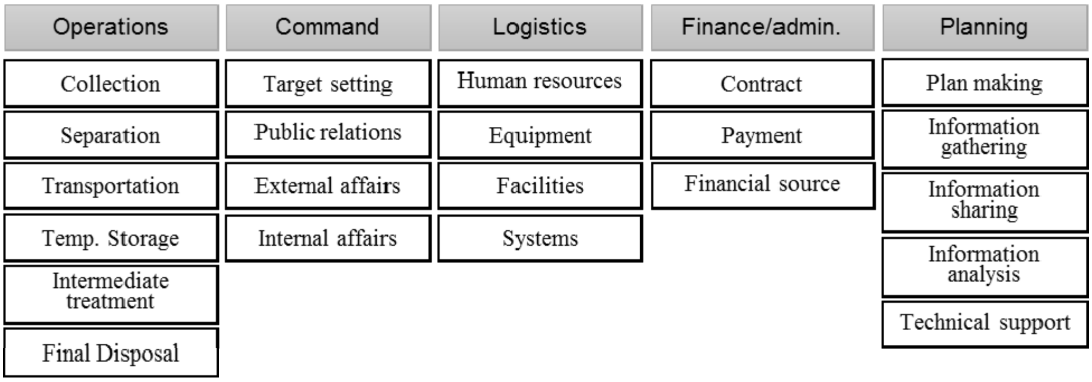

Fig. 17.2 Disaster waste management functions (source: Tajima et al., 2014b, translated)

Applying this empirically tested set of DWM functions, local governments can design response actions and functional organizations ahead of disasters as an important part of preparedness planning. However, in the absence of a thorough understanding of the aims and principles of preparedness planning, there is a possibility that such planning may not actually lead to effective DWM. This outcome, in fact, was partially evident in the case of the Tohoku Earthquake, with many local officers claiming that their preparedness plan for DWM was not effective. Various reasons were given for this, such as ambiguity in the writing of the plan and assumptions made about natural disasters that radically differed from what actually happened. To enhance effective preparedness planning for DWM, six principles were established, as summarized in Fig. 17.3, based on the existing literature on disaster/waste management and interviews conducted with 10 waste management officials within Japanese local authorities. These guiding principles were as follows. (1) Emphasize the process rather than the product (the written plan). (2) Coordinate and communicate with relevant actors throughout the planning process. (3) Use accurate knowledge regarding disaster agents and responses. (4) Focus on general principles rather than on specifics to allow for flexibility. (5) Consider sustainability issues (e.g., environmental impacts). (6) Keep the entire disaster management cycle in mind (from response to recovery, mitigation, and preparedness), as this would lead to the development of DWM competency in the locality, and consequently, to smooth and appropriate DWM.These principles had been partially validated through an evaluation of a Japanese DWM case. The results suggest that: (1) the principles are useful in highlighting the strengths and weaknesses of DWM planning in practice, and 2) while *pro forma* establishment could increase the number of DWM plans, without an ongoing process of DWM planning, this will not contribute to improved preparedness.

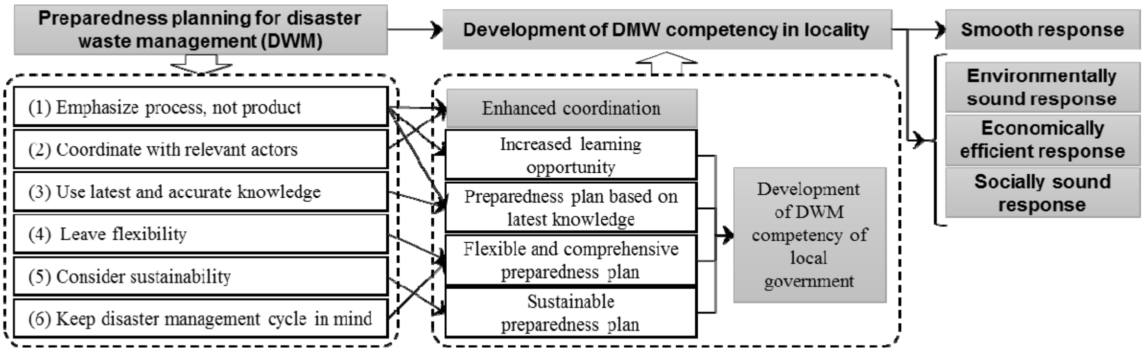

Fig. 17.3 Principles of preparedness planning for disaster waste management(source: Tajima et al. 2013).

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