Recommendations

Toward Making a New Step Forward in Radiation Measures - Taking Actions based on Fact-based Scientific Research -

April 9, 2012

Science Council of Japan

Committee on Supporting Reconstruction
after the Great East Japan Earthquake

Sub-Committee on Counter-measures for Radiation

These recommendations compile and publish the results of deliberations of the Sub-Committee on Counter-measures for Radiation, Committee on Supporting Reconstruction after the Great East Japan Earthquake, Science Council of Japan.

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Summary

1 Background to the recommendations

The Great East Japan Earthquake that occurred on March 11, 2011 off the Pacific Ocean of the Tohoku Region was the 4th largest earthquake recorded in human history. It was a very complex disaster because of an accident that occurred at the Fukushima Daiichi (No. 1) Nuclear Power Station of Tokyo Electric Power Co., Inc. (TEPCO) which was triggered by a total loss of power after seven Tsunamis extending from 30 minutes to 6 hours after the earthquake occurred, thereby resulting in serious amounts of damage.

The human damage and property damage resulting from the Tsunami disaster were both unfathomable, while the disaster also deprived the disaster victims/disaster-stricken areas of both their residences and places to work. Despite having the severe psychological trauma and had their lives inconvenienced by having to live at temporary housing the victims are still proceeding with restoration/reconstruction activities in thereby realizing a permanently safe society. When reconstructed they must be "communities resilient to disasters" in a multi-faceted sense. In addition, people cannot make a living unless industries that can sustain the disaster-stricken areas steadily take root, with job opportunities then being ensured by those industries. Furthermore, and with regard to the nuclear power plant accident, completion of its final disposition may require a time span of more than one generation. Many people have been forced to evacuate for an extended period of time, thus establishing a long-term health management system for those who fear having been exposed and decontamination measures in the areas where radioactive materials were deposited are posed as imminent issues.

These various reconstruction challenges thus require the specific provision of desperately needed knowledge to the victims through mobilization in the various fields of science, which is precisely the duty of Science Council of Japan (SCJ). The 21st Term SCJ made the commitment soon after the occurrence of the great earthquake by setting up the Great East Japan Earthquake Task Force, issuing urgent recommendations on seven consecutive occasions, and so on. At the inception of the 22nd Term SCJ in October 2011 the Committee on Supporting Reconstruction after the Great East Japan Earthquake was established to succeed the Great East Japan Earthquake Task Force. On November 16, the Sub-Committee on Building Disaster-Resilient Communities, the Sub-Committee on the Promotion of Industry and Employment, and the Sub-Committee on Counter-measures for Radiation were set up under the said Committee.

The Sub-Committee on Counter-measures for Radiation considers identification/analysis of the present situation with and future transition of radioactive contamination and effective

dissemination of what can be done to prevent health damages to be an urgent issue.

2 Present situation and issues

Estimating the present situation with and future transition of contamination from radioactive material resulting from the Fukushima Daiichi Nuclear Power Plant accident necessitates the review on the course of the accident and systematic implementation from a) estimation of the period of radioactive material emission from the nuclear power plant and total amount of emissions, b) identification of the environmental distribution/transition of radioactive materials, c) comprehensive identification of exposure routes to human victims by period and place, d) estimation of the respective victim's radiation exposure time and exposure doses through the comprehensive identification, through to e) assessment of potential subsequent health effects as the result of exposure. The necessary information to fulfill these tasks, however, was not necessarily managed/provided in an integrated manner. The data and information, although very precise, were divided and managed by respective administrative agencies, research institutions, and researchers, and disclosed in forms that did not allow for easy cross-sectional sharing.

Thus, the Sub-Committee aimed to respond to the anxiety of the residents in the neighborhood of the Fukushima Daiichi Nuclear Power Plant and the Japanese people in general to the fullest extent possible within a limited period of time by a) putting together all the separate information, b) revealing the perspective of where and in what form the information sources should be stored, and then c) estimating the resulting health effects through connecting that information. A provisional estimation, although based on the limited data and information available at present, also suggested the importance of appropriate management of cumulative radiation doses in thereby accurately identifying future health concerns. Furthermore, and in the course of these discussions, minimizing the effects of exposure and more precisely estimating negative health effects due to exposure were shown to be in urgent need.

3 Content of the recommendations

Based on the exposure dose and health effects estimated for different exposure routes the following six recommendations will be provided here in helping to minimize health effects and improving the assessment of health effects due to radiation exposure.

Recommendation 1:

The government/municipalities shall continue to estimate exposure doses and provide medical checkups/examinations to residents in thereby protecting the health of those already exposed to radiation, and children and infants in particular. For this purpose, the government/municipalities shall establish a system that can provide thyroid ultrasound examinations and blood tests, along with a regional medical system that enables residents to receive appropriate and prompt treatment in the case of health abnormalities being detected.

Recommendation 2:

The government/municipalities shall implement appropriate measures such as establishing decontamination targets, including the post-return of residents and management of decontamination work, etc., in order to prevent the cumulative exposure doses from reaching the level that could pose a negative health effect because of potential further exposure due to their return/decontamination work.

Recommendation 3:

Academic circles in Japan shall plan appropriate epidemiological research on estimating the radiation dose-response curve with respect to the carcinogenic rate and cancer mortality rate, implement it in cooperation with the government/municipalities, promote an integrated understanding with other basic research, and promptly reflect the results in the health management of the residents.

Recommendation 4:

The government and academic circles in Japan are requested to cooperate in establishing a cross-disciplinary research system that can be used to identify the overall picture related to the assessment of radioactive health effects and in thereby more accurately identifying the actual situation with radiation contamination and health effects associated with the Fukushima Daiichi Nuclear Power Plant accident and appropriate implementation of decontamination and health effect prevention measures.

Recommendation 5:

he government shall establish a system that enables the prompt and steady collection of data required in looking back on the accident and data which will have a significant effect on the accuracy when estimating health effects, and also a public system for providing standardized data in a form that most readily allows researchers to use/analyze it.

Recommendation 6:

Institutions/researchers engaged in radiation-related measurements or model-based estimations are expected to disclose the results of the various measurements/estimations used as basic figures in assessing radioactive health effects together with uncertainty information. In addition, accuracy control or improvement of the measurement/estimated results based on uncertainty information will need to be planned and implemented.

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1 Introduction

The 4th biggest earthquake recorded in human history, with a moment magnitude of 9.0 off the Pacific Ocean of the Tohoku Region, took place on March 11, 2011. Seven Tsunamis that extended from 30 minutes to 6 hours after the earthquake then resulted in enormous damage to the coastal areas of the Tohoku and Kanto Regions, in Iwate, Miyagi, Fukushima, Ibaraki, and Chiba Prefectures in particular.

There are a total of six power plants, Units 1-6, of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Co., Inc. (hereinafter referred to as the Fukushima Daiichi Nuclear Power Plant) that commenced operation during 1971-1979 with the electricity output of Unit 1 being 460,000 kilowatts, Units 2-5 784,000 kilowatts, and Unit 6 1,100,000 kilowatts. The first high wave of the Tsunamis reached the Fukushima Daiichi Nuclear Power Plant at around 15:27 and the second at 15:35, with the height of the Tsunamis reaching a maximum of 15 meters.

The Fukushima Daiichi Nuclear Power Plant accident that resulted from the Tsunamis resulted in the emission of a vast amount of radioactive materials which then led to contamination of wide areas of national land and ocean, while also posing the risk of radiation exposure†[18] to many Japanese people, mainly neighborhood residents. After the issuance of an evacuation order to the residents in areas within a 20-kilometer radius of the Fukushima Daiichi Nuclear Power Plant on March 12 almost 100,000 people, including voluntary evacuees, had their daily lives suddenly interrupted and were forced to leave their home, workplaces, and in some cases families to live in the evacuation areas. In addition, many people were worried about potential health effects due to radiation exposure that may have continued since immediately after the accident to date, and grew anxious about not only their own futures but also those of their children and grandchildren.

The Sub-Committee thus regarded assessing the effects of exposure to radioactive materials on the residents' health through estimating the present situation with and future transition of contamination by radioactive materials from the nuclear power plant accident and making recommendations on the means of alleviating those effects to the fullest extent possible to therefore be an extremely urgent issue.

The Sub-Committee considered that it would necessitate the course of the accident being reviewed and systematic implementation of estimation of the period of radioactive material emission from the Fukushima Daiichi Nuclear Power Plant and total amount emitted,

[18] Hereinafter refer to <Definition of terms> for words and phrases marked with †.

comprehensive identification of the environmental distribution/transition of radioactive materials and exposure routes to human victims by period and place, estimation of radiation exposure time and exposure doses, and assessment of potential subsequent health effects. The necessary information for these tasks, however, was not necessarily managed/provided in an integrated manner. The work of the Sub-Committee revealed the data and information, although very precise, to have been separated and managed by respective administrative agencies, research institutions, and researchers, and to thus have been disclosed in forms that did not allow for easy cross-sectional sharing of it.

The Sub-Committee therefore aimed to respond to the anxiety of residents in the neighborhood of the Fukushima Daiichi Nuclear Power Plant and the Japanese people in general by collating all the separated information to the fullest extent possible and within a limited period in thereby pinpointing the perspective of where and in what form the information sources are stored and predicting the resulting health effects through connecting that information. Furthermore, and based on the results of the discussions, the Sub-Committee issued recommendations for use in minimizing the effects of exposure and making more precise predictions of the health effects due to exposure.

2 Approaches used in these recommendations

(1) Outline of approaches used in these recommendations

Outline of ways of thinking

[1] Total emitted amount of radiation resulting from the nuclear power plant accident that then led to radiation exposure

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[2] Distribution of total emitted amount of radioactive materials to the environment

- Estimated distribution and measured distribution in the sea, atmosphere, soil, and rivers
- Nuclear species and decay
- Predicted transition of contamination with future environmental circulation and concentrations taken into account

etc.

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[3] Comprehensive identification of exposure routes to humans

- Form of exposure (relatively high level of radiation over a short period after the accident vs. low level radiation over mid- to long-periods)
- Routes of exposure (external exposure vs. internal exposure)
- Exposure dose by location/period
- Exposure time

etc.

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[4] Estimation of exposure doses to date, and assumed exposure doses hereafter

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[5] Assessment of effects on human health

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[6] Recommendations in preventing any health damage to the fullest extent possible (concrete measures and estimation of effects)

- Decontamination
- Inspection of water and food
- Early detection of any abnormalities by monitoring people's health and provision of appropriate medical care etc.

As revealed by the "outline of ways of thinking" given above the Sub-Committee aimed to provide prototype processes for estimating the total emitted amount of radioactive materials from the Fukushima Daiichi Nuclear Power Plant ([1]), connecting separated information on environmental transitions ([2], [3]), exposure doses [4], and assessment of health effects ([5]), and predicting the resulting health effects. Through this the Sub-Committee was to determine the effectiveness of connecting all the information, specify any data urgently needed and any uncertainties that could significantly affect the results, and discuss the necessity of identifying information in an integrated manner.

In predicting at this time the extent and level of effects on the residents' health due to the accident the following two works, in particular, were important.

1) Reflecting the results of assessing the abovementioned emitted amounts and diffusion obtained in the field of science and engineering, including atomic, meteorology, oceanic, and simulations, etc., in the assessment of exposure doses obtained in the field of medicine/public health, including radiology and food safety, etc. and predictions
2) Estimating the extent and level of potential health effects in the future through integrating the predicted exposure doses from 1) into precedence research in the field of radiology.

In these recommendations efforts were made to link the exposure dose assessments to the emitted amount and diffusion assessments[19].

More concretely, the overall perspective, from the emission of radioactive materials to the effect on human health, although mainly for "[2] Distribution of total emitted amount of radioactive materials to the environment" from the outline of ways of thinking above is provided in Chapter 3 of these recommendations. "[3] Comprehensive understanding of exposure routes to humans" is discussed in Chapter 4, and "[4] Estimation of exposure doses to date, and assumed exposure dose hereafter" and "[5] Assessment of effects on human health" in Chapter 5.

(2) Scope of discussion and definition

[1] Definition of time base

Comprehensive understanding of exposure to radioactive materials emitted to the environment due to the accident requires, primarily, setting the time base of when, i.e. how long after the accident, and how long the exposure took place. This is an issue common to

[19] Due to the limited time available to put together these recommendations the assessment of the exposure doses could not be integrated into the assessments of the emitted amounts and diffusion, and in the form of connecting the results of a certain stage as input values for the next stage. The same monitored data of radiation doses in the air was used, however, as evidence to verify the emitted amounts, diffusion, and exposure doses, and thus no significant inconsistencies are considered to exist between the different stages.

both internal and external exposure. Setting the time base requires consideration of

a. Period and duration of radioactive material emission from the nuclear power plant,

b. Physical half-life† of the nuclear species† emitted and half-life of internally exposed nuclear species inside the human body, and

c. Scale of phenomenon in the natural environment, including advection, diffusion, deposition, and inter-media transfer.

Furthermore, with this accident while some cases of people immediately evacuating within a short time after the accident exist there are also cases where people remained in areas of relatively high radiation doses for a certain period and then evacuated, and the return of resident after decontamination is being planned for areas where those residents are evacuated at present. The time scale of the transfer of those residents is therefore also considered to be an important factor. The half-life of cesium 137 (hereinafter referred to as ^{137}Cs), a major nuclear species of concern with long-term exposure, is approximately 30 years and hence a time scale of at least several decades needs to be considered. In contrast to this however the duration of high radiation during the passage of a radioactive plume† only lasted about an hour in some cases. These recommendations use break values of three hours, three days, three weeks, three months, three years, and 30 years to illustrate immediately after and over the short/medium/long-term as model time scales in thereby identifying the exposure resulting from the various time scales. The classification of Table 1 is used to indicate the contribution ratio to cumulative exposure dose.

Table 1 Exposure time scale and major factors to be considered

Classification	Model time scale	Factors in emission and environmental factors	Factors in exposure
Immediately after*)	3 hours to 3 days	Changes in emission, advection paths of the plume, and behavior of short-lived nuclear species containing rare gases	Residential area, and transfer for evacuation purposes (Distinction between indoor and outdoor is also important)
Short-term	3 days to 3 months	Behavior of short-lived nuclear species such as iodine, etc., period of cesium deposit, and geographical distribution	Residential area, and transfer for evacuation purposes
Medium-term	3 years	Precise identification of radiation dose distribution, re-scattering and concentration, and effectiveness of decontamination	Residential area, and food intake (Participation in decontamination work)
Long-term	30 years	Transfer of radioactive materials within environmental media	Return from evacuation area, residential area, and food intake

*) Including not only the large amount of emissions on March 15 but also the emissions deemed to have taken place on around March 20-22, although three days or more had elapsed, and to the scope of immediately after is considered appropriate.

[2] Definition of geographical zone

The results of wide-area observations[20] reveals a rather complex geographical distribution of the deposited amount of radioactive materials to the ground surface and radiation dose rates in the air through advection/diffusion in wind and deposition due to rainfall/snowfall, etc. However, measured data that reveals the behavior of the radioactive plume immediately after the accident is rather limited and thus estimated values using modeling were mainly used. In addition, and as shown in Table 2, consideration also needs

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[20] Airborne monitoring by the Ministry of Education, Culture, Sports, Science and Technology (including joint monitoring with the U.S. Department of Energy)
http://radioactivity.mext.go.jp/old/ja/monitoring_around_FukushimaNPP_MEXT_DOE_airborne_monitoring/

to be given to activities with regard to transfer of the exposed subjects.

In any case precise estimation of the amount of exposure requires the geographical distribution to be taken into account. These recommendations adopt the approach of estimating the exposure dose by establishing several geographical zones and setting representative scenarios for each zone.

Table 2　Geographical zones used in setting exposure scenarios

Classification	Radiation dose rate in the air and additional exposure dose	Matters of particular concern with the scenario
Zone A A zone with an additional annual exposure dose before decontamination of around 50 mSv	50 mSv/y (10 μSv/h) 10-20 mSv/y after decontamination	・ Exposure during transfer for evacuation purposes ・ Exposure at the evacuation area ・ Decontamination level, and exposure after return
Zone B A zone with an additional annual exposure dose before decontamination of around 20 mSv	20 mSv/y (4 μSv/h) 5-10 mSv/y after decontamination	・ Exposure during the period between the accident and the date of evacuation ・ Exposure at the evacuation area ・ Decontamination level, and exposure after return
Zone C A zone with an additional annual exposure dose before decontamination of around 5 mSv	5mSv/y (1μSv/h)	・ Thorough investigation of the situation with exposure immediately after the accident ・ Exposure at residences and during commuting ・ Exposure accompanying decontamination activities
Zone D A zone with an additional annual exposure dose before decontamination of around 2 mSv	2 mSv/y (0.4μ Sv/h)	・ Exposure at residences and during commuting ・ Exposure accompanying decontamination activities
Zone E A zone with an additional annual exposure dose of around 0.5 mSv	0.5 mSv/y (0.15 μSv/h)	・ Exposure at residences and during commuting ・ Exposure accompanying distribution of food, etc.
F) A zone with little accident-related deposition	Background (0.05 μSv/h)	・ Exposure accompanying distribution of food, etc.

Note 1　The deposited amount of $^{134}Cs+^{137}Cs$ per unit area was estimated to be around

2500kBq/m^2 in Zone A, 1000kBq/m^2 in Zone B, 250kBq/m^2 in Zone C, 100kBq/m^2 in Zone D, and 25kBq/m^2 in Zone E. Bq† indicates becquerel.

Note 2 Zone A and Zone B fall under being classified as a caution zone and planned evacuation zone, respectively, and decontamination of these zones will be assumed to be carried out by the government in accordance with the Act on Special Measures concerning the Handling of Contamination by Radioactive Materials. Zone C and Zone D fall under being classified as priority areas for the radioactive contamination surveys provided for in the Act on Special Measures, and decontamination of these zones will be assumed to be carried out by the local governments.

[3] Subjects of exposure risk assessments

From the point of view of the absolute level of exposure doses, and the short-term exposure dose immediately after the accident, in particular, attention should probably be paid to those working to restore the situation after the accident at the nuclear power plant, but these recommendations assumed the disaster-victim residents to be the subjects when the assessing the exposure risks. However, workers at risk of additional exposure resulting from radioactive material emission due to the accident, for example those engaged in decontamination work or at waste disposal facilities, are included as the subjects for discussion. In addition, residents can participate in decontamination work in some cases and therefore a focus should also be placed on the effects of decontamination on those residents.

[4] Nuclear species subjected to assessment

The aspect of the contribution to exposures dose of each nuclear species is considered to be different with each of the time bases given in Table 2. Judging from actual measured results obtained to date the contribution was the largest with ^{137}Cs over the long-term, with cesium 134 (hereinafter referred to as ^{134}Cs) being at the same level or more important than ^{137}Cs over the medium-term. Examining the emitted amount at the time of the accident in becquerel (hereinafter referred to as Bq†) reveals the ratio of ^{134}Cs and ^{137}Cs to have been 1:1, but the emitted gamma ray energy to have been larger with ^{134}Cs, and thus the initial exposure contribution was larger with ^{134}Cs. The half-life of ^{134}Cs is significantly shorter at two years than that of ^{137}Cs at 30 years. The radiation dose† from cesium (^{134}Cs + ^{137}Cs) therefore drops by almost half over the first three years. (Figures 1 and 2)

In contrast to this iodine 131 (hereinafter referred to as ^{131}I) is considered important with respect to the short-term exposure immediately after the accident. In addition to its significant contribution to external exposure it is known to accumulate in the thyroid when internally exposed to it. It was successively detected in both the water supply and food immediately after the accident.

Various monitoring media used after the accident also focused on ^{134} Cs, ^{137}Cs and ^{131}I, with precedent measuring of other species being limited, but there are some species that cannot be ignored in the assessment of exposure immediately after the accident in particular. According to data measured in Chiba City by the Japan Chemical Analysis Center <1> the contribution of xenon 133 (hereinafter referred to as ^{133}Xe), a rare gas, to initial external exposure was large. ^{133}Xe is a member of a nuclear species group referred to as a submersion nuclear species but which does not accumulate in the human body, and thus is not considered important as an internal exposure source. Clarifying whether a sharp rise in the radiation dose rates in the air observed immediately after the accident in various areas, which was considered to have been caused by the passage of a radioactive plume, was due to ^{133}Xe or ^{131}I is an extremely important issue in estimating the exposure dose and health risks.

In addition, the detection of some nuclear species, including tellurium, barium, strontium, and plutonium, etc. has been reported[21], but with food safety standards their contribution to the exposure dose is considered to have been around a total of 10%.

[21] Tellurium (^{129m}Te, ^{132}Te), ^{133}I, and ^{136}Cs were detected in measurements made by the High Energy Accelerator Research Organization (KEK) in Tsukuba City and National Institute for Environmental Studies and zinc (^{65}Zn), niobium (^{95}Nb), silver (^{110m}Ag), ^{136}Cs, barium (^{140}Ba), and lanthanum (^{140}La) in the fallout measurements made by the Ministry of Education, Culture, Sports, Science and Technology. In contrast to this, and judging from measurements of soil within Fukushima Prefecture, the contribution of long-life nuclear species, and strontium (^{90}Sr) in particular, which is considered important from the point of view of accumulation in the human body, to the exposure dose was deemed to be smaller than Cs, although more substantial measured values are needed in ensuring a more precise assessment of the exposure dose. Furthermore, nuclear species such as plutonium (Pu) and tritium (^{3}H), etc. are of public interest, with plutonium 241 (^{241}Pu), which is considered to have originated from the nuclear power plant accident because of its half-life, having also been reported. Data made available by the Ministry of Education, Culture, Sports, Science and Technology resulted in maps for ^{238}Pu and ^{239}Pu+^{249}Pu then being disclosed on September 30, 2011, with the estimated cumulative radiation doses over 50 years at the locations where the maximum values were observed being ^{134}Cs: ^{71m}Sv, ^{137}Cs: 2000mSv, ^{238}Pu: 0.027mSv, ^{239}Pu+^{240}Pu: 0.12mSv, ^{89}Sr: 0.00061mSv, and ^{90}Sr: 0.12mSv. Furthermore, maps of ^{129m}Te and ^{110m}Ag were disclosed on October 31, 2011 and with the estimated cumulative radiation dose over 50 years at locations where the maximum values were observed being ^{129m}Te: 0.6mSv and ^{110m}Ag: 3.2mSv.

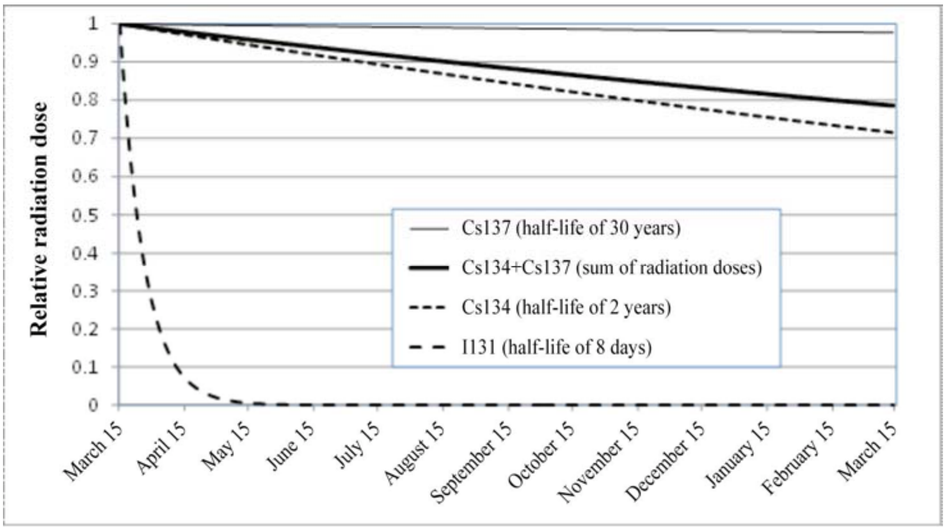

Figure 1 Theoretical value of radiation decay calculated from half-life (1)

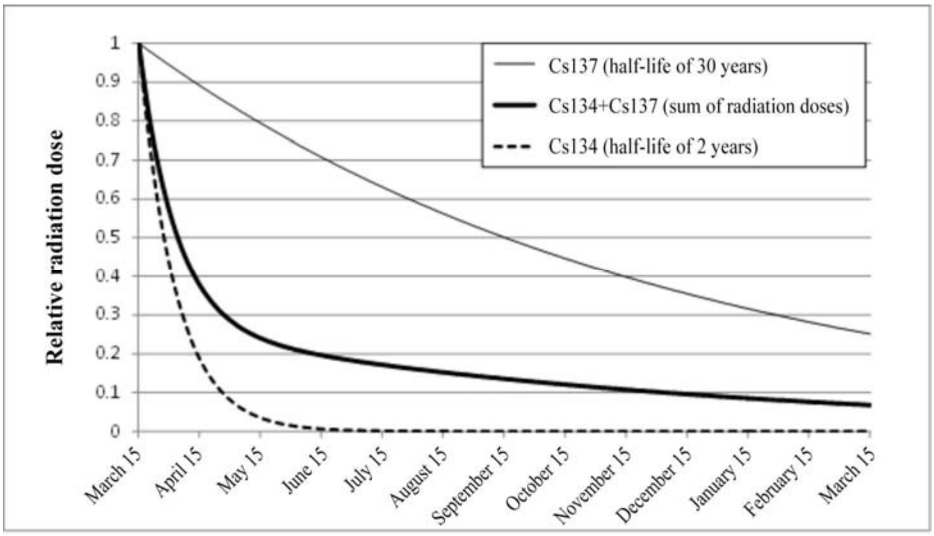

Figure 2 Theoretical value of radiation decay calculated from half-life (2)

3 Overall perspective from emission to health effects

(1) Course and outline of accident

Heat is generated in nuclear reactors from the radioactive decay of nuclear species inside the nuclear fuel, and even when the reactors are not in actual operation. Without continued cooling, therefore, the temperature continues to rise, with chemical reactions between the cladding material of nuclear fuels and water leading to further temperature rises, and which can then damage the fuel cladding tubes and generate hydrogen. For this reason nuclear power plants require a variety of cooling systems. In the case of Fukushima Daiichi Nuclear Power Plant, however, the power transmission line facilities were destroyed by the earthquake and external power was no longer available. In addition, emergency diesel generators stopped operation when the Tsunamis hit the plant, thereby resulting in the entire AC power functions being lost except for Unit 6. Sea water pumps used to release heat to sea water were also no longer functioning, thus resulting in the loss of the final heat removal function to the sea. DC power also did not last long due to the loss of its functions or exhaustion of its power supply. This led to the loss of the cooling functions and subsequent damage to the fuel as well as hydrogen generation and then a hydrogen explosion. In addition, venting was carried out to reduce the pressure inside the containment vessel.

A large quantity of radioactive materials was released during the period of March 15 through to 16, but with high radiation dose rates then occasionally being observed in the neighborhood of the Fukushima Daiichi Nuclear Power Plant for two weeks after the accident. Many of these events matched the period when venting took place from the respective units and the period when the building housing the nuclear reactor was blown apart as a result of the hydrogen explosion. In many cases rises in the radiation dose rate were observed when containment vessels were vented and the building housing the nuclear reactor collapsed, but some of it also matched the period when vapor was released into water inside the pressure suppression chamber using safety relief valves and the period of the deemed external diffusion of radioactive materials in vapor through damaged areas of the containment vessel due to intensive vaporization resulting from water being added to high temperature fuel in hot vessels containing no water. In addition, later analysis of the radiation measurements results indicates continuous releases of large quantities of radioactive material until the beginning of April.

(2) Four assessments and a figure providing an overall perspective

The following four assessments need to be carried out for use in predicting the radiation exposure of the residents in the neighborhood of the nuclear power plant and the Japanese people in general, and its health effects, all of which is of concern and to have resulted from the accident.

1) **Assessment of emitted amounts**: estimating when, what type, and what quantities of radioactive material were emitted from the nuclear reactors into the atmosphere, land, and ocean
2) **Assessment of diffusion**: estimating how the radioactive materials emitted from the nuclear reactors diffuse into the surrounding environment and when, where, and in what quantities they were transported and deposited, and estimating the future situation
3) **Assessment of exposure doses**: estimation of the direct exposure doses by estimating when and in what quantities of diffused radioactive materials people were exposed to and then predicting possible future long-term exposure, along with indirect exposure doses, including internal exposure due to intake of food contaminated by radioactive materials and external exposure due to transfer of radioactive materials, etc.
4) **Assessment of health effects**: estimation of the level of increased possibility of the occurrence of cancer and other diseases with people who were exposed to radiation resulting from the nuclear power plant accident

The above four tasks and the major data then available need to be reviewed, as shown in Figure 3, and the respective assessments then integrated. The next chapter presents what types of relevant data are available in accordance with the assessment stages, while also providing the observations of the Sub-Committee.

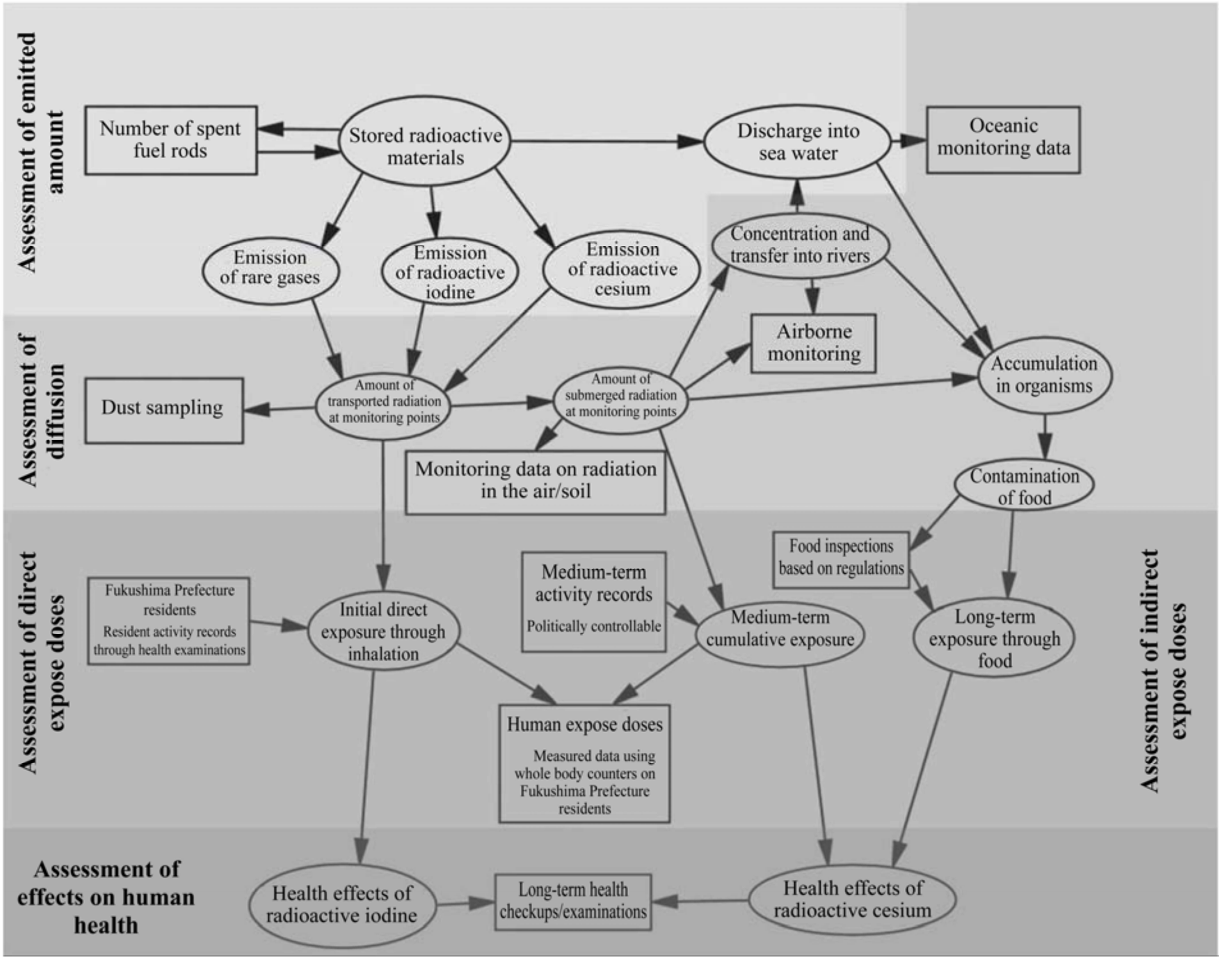

Figure 3 Simple view of short-term/long-term exposure and health effects

Note: Ovals indicate major incidents and rectangles major information

4 Comprehensive identification of exposure routes to residents and estimation of relative contribution ratio

(1) Estimation of emitted amounts

Conceivable emissions of radioactive material due to the Fukushima Daiichi Nuclear Power Plant accident include emissions into the air and discharge into the ocean/ground water. Present major emissions in relation to the assessment of effects on human health are considered to be emissions into the air, which is related to both external exposure and internal exposure through inhalation as well as indirect internal exposure through intake of exposed agricultural products, and discharge into the ocean, which is related to internal exposure through intake of marine products. Representative data on the estimated emitted amounts into the air and estimated discharged amounts into the ocean is presented here. Precise data on the direct discharge from the nuclear reactors into the ground water are not available at present.

[1] Emissions into the air

The following two estimation methods were basically adopted for use with the amount of emissions into the air because directly measured data inside the nuclear reactor facilities was incomplete, mainly for the period of large scale emissions. The Nuclear Emergency Response Headquarters put together this data and reported the estimated results to be 1 to 2×10^{17}Bq for ^{131}I and 1 to 2×10^{16}Bq for ^{134}Cs and ^{137}Cs to the International Atomic Energy Agency <2>.

a. Estimations based on the results of analyzing the state of the nuclear reactors

The Nuclear and Industrial Safety Agency disclosed the estimated emitted amounts based on observed data from the plant immediately after the earthquake and the results of analyzing the state of the nuclear reactors in Units 1-3 <3>. According to corrected data made available on May 18, 2011, it was ^{131}I : 1.6×10^{17}Bq (2.0×10^{16}Bq for Unit 1, 1.4×10^{17}Bq for Unit 2, and 7.0×10^{15}Bq for Unit 3), ^{134}Cs : 1.8×10^{16}Bq, and ^{137}Cs : 1.5×10^{16}Bq <3>.

The estimation using this method resulted in the emissions from the respective units to have been deemed to have converged by March 16 after the emissions from Unit 2 on March 15, 2011, and with no estimation for additional emissions after March 16 being possible <3>.

b. Inverse estimation from environmental monitoring data

The estimation made by the Japan Atomic Energy Agency (hereinafter referred to as JAEA) utilizes an inverse estimation using WSPEEDI-II†, which enables integration of a simulation of the diffusion of radioactive materials in the air that reflects the weather conditions via the use of monitoring information. The estimated values corrected on August 22, 2011 by adding the information at monitoring posts for the period between May 12-15, 2011 <4> were ^{131}I : 1.3×10^{17}Bq and ^{137}Cs : 1.1×10^{16}Bq. JAEA reported that measurable emissions continued to at least up to April 5, 2011, while overseas research <5> also reported similar changes in the emissions.

[2] Discharge into the ocean

Data is available on the discharge into the ocean, with the estimated discharged amount being based on directly measured data on the discharge of contaminated water from the Fukushima Daiichi Nuclear Power Plant <6>. According to the inverse estimation and using a simulation of the offshore diffusion and sea area monitoring data conducted by the Japan Meteorological Agency <7> the major discharge dropped after the beginning of April but had not reached zero as of the end of August. The cumulative discharged amount of ^{137}Cs during the period between March 26 and May 31 was reported to be (3.5±0.7)×10^{15}Bq, which is, however, inconsistent with the amount in <6> that was estimated from the directly observed discharged amount. The inverse estimation, however, does include issues with submergence into the ocean from the air and separation of materials originating in nuclear tests, etc. In contrast to this, and according to the discharged amount as estimated by JAEA, the amount of directly discharged ^{137}Cs into the ocean was 3.6×10^{15}Bq (^{131}I:1.06×10^{16}Bq and ^{134}Cs:3.5×10^{15}Bq) <8>.

(2) Diffusion of radioactive materials into land, air, water, and solids

[1] Distribution of initial fallout due to air diffusion

Radioactive materials emitted from the source get transported as gaseous materials or particulate materials and eventually deposited on the land and sea via dry deposition (gravity fall and vertical transport due to turbulent airflows, etc.) and wet deposition via rainfall. According to the results of calculations using several high granularity models, including WSPEEDI-II, etc., 25% to 37% of ^{137}Cs was considered to have been deposited on Japanese land from 32 to 42 degrees north latitude <9-13>. The diversity seen in this assessment is due to the difference in the assumption of the scavenging rate due to rainfall, assumption of temporal changes in the emitted amount, and the results of calculating meteorological fields, thus necessitating that a comparison of the different models of other nuclear species take place and that the simulation errors be reduced in the future. However, the transportation mechanisms of the major emissions in March (15-16th and 20-21st of March, etc.) were almost completely identified using data analysis and model simulations.

[2] Current status with mapping of radioactive nuclear species fallout

Using the recommendation “necessity of the investigation of radiation levels after the accident of the Fukushima Daiichi Nuclear Power Plant” <14>, which was issued by SCJ on April 4, 2011, as a start point a joint team composed of the Ministry of Education, Culture, Sports, Science and Technology and universities collected 5 centimeters of the topsoil layer from around five sampling points in approximately 2,200 locations within an approximately 100-kilometer radius of the Fukushima Daiichi Nuclear Power Plant and then analyzed the nuclear species found in that soil <15>. Approximately 11,000 soil samples were collected, and the deposited amounts (radiation dose per unit area) of five gamma-ray emitting nuclear species, namely ^{134}Cs, ^{137}Cs, ^{131}I, ^{129m}Te, and ^{110m}Ag, then measured using a germanium semiconductor detector, and a map of the concentrations of the respective radioactive nuclear species in the soil created.

A later comparison of the measurement results of airborne monitoring with the deposited amounts found in the soil proved to be consistent, and thus the subsequently conducted airborne monitoring over the whole of East Japan can also be regarded to have reproduced rather accurate deposited amounts. The results of measurements made via airborne monitoring can therefore be regarded to be useful as basic data for use in comprehensively identifying the exposure routes to residents, the actual situation with and the dynamics of radioactive materials, and estimating the emitted amount into the air, etc.

[3] Process of transfer, diffusion, and concentration of the amount of fallen radioactive nuclear species on land

Radioactive material fallout on the land surface identified to have been transferred through the natural environment, including forests, soil, and rivers, etc. A report prepared by the Ministry of Education, Culture, Sports, Science and Technology <16>, in which the Yamakiya region, Kawamata town, Date county located in the upper reaches of the Kuchibuto River of the Abukuma River system was selected to be the model region, with the report being as follows.

1) The transfer of radioactive cesium to soil water, running water, and underground water was observed to be small as of February 2012.
2) In coniferous forests a large amount of radioactive cesium existed in the canopies, with that radioactive cesium being gradually transferred to the forest bed in the

process of passage through the canopies of rain that fell on the forests.

3) With regard to the amount of fine soil and sand particles discharged into rivers the discharge of soil and sand of no more than 0.3% of the amount of radioactive cesium fallout into rivers was verified, even with bare land with little vegetation, but the amount of discharge of radioactive cesium was rather small with pastures and forests. With rice paddy fields the discharge into rivers mainly took place when the fields were being prepared.

4) Over 90% of radioactive cesium flowed into rivers in the form of floating sand, and a maximum total concentration of ^{134}Cs and ^{137}Cs of 10,000 Bq/kg or more, which far exceeded 10 times the regulated value for sludge, was observed at many locations in the main stream of the Abukuma River. In addition, soil and sand of the same level of high concentration accumulated in the reservoir in the main stream of the Abukuma River. A positive correlation was identified between the average concentration of radioactive cesium in soil collected from the upper reaches and the concentration of radioactive cesium in river-bed soil after making particle size adjustments, which thereby took the adsorption rate of radioactive cesium on fine particles into account.

The characteristics of the transfer of radioactive cesium indicate that the radioactivity concentration of radioactive cesium in river water, river-bed soil, and floating sand at specified sampling points can be considered to be capable of being estimated if the average deposited amount of radioactive cesium in the upper reaches of the water sampling locations is obtained through utilizing a map of the deposited amount of radioactive materials. However, quantification of re-scattering mechanisms and transfer to vegetation of radioactive materials will be needed over the long-term.

[4] Process of advection diffusion of radioactive nuclear species in the ocean

Radioactive nuclear species emitted to the air, and approximately 2/3 of the radioactive cesium in particular, were estimated to have been transported to the ocean and deposited on the surface of the ocean, and thus becoming the source of radioactive materials in the ocean. Radioactive cesium has been widely detected at the surface of seawater in measurements made by oceanographic research vessels, etc. that cross the North Pacific Ocean, etc. since the beginning of April. The locally measures value was 196 Bq/m^3 for ^{137}Cs, which was higher by two digits than that in surrounding waters <17>. This was considered to be due to fallout from the air via rainfall.

Radioactive materials directly discharged from the Fukushima Daiichi Nuclear Power

Plant into the ocean get diffused through rather complex routes that are affected by ocean currents and the wind. Oceanic monitoring took place at a relatively early stage, and which identified that 100 Bq/L or more of ^{137}Cs had been diffused to the north and south along the coast of Fukushima Prefecture in late March and then gradually diffused to offshore in and after mid-April. However, the granularity in terms of time and space was rather coarse, thus making identifying a detailed advection diffusion situation from the observed data rather difficult. In addition, and from the results of a consistent numerical simulation, part of the radioactive materials will have reached the international date line around six months after the discharge, but was estimated to be considerably diluted to a concentration of approximately 0.01 Bq/L.

(3) Exposure routes

Major radiation exposure and health effects due to the emission of radioactive materials that accompanied the accident can be listed in chronological order as follows.

1) **Short-term direct exposure**: caused by radioactive materials, including those with a short half-life, emitted from the Fukushima Daiichi Nuclear Power Plant during the period of between March 12 and the beginning of April and which directly adhered to the human body or was inhaled.
2) **Long-term direct external exposure**: caused by radioactive materials emitted from the Fukushima Daiichi Nuclear Power Plant, including radioactive cesium with a long half-life, etc., deposited in residential or work environments used in daily life or at work. In addition, this type of exposure can also occur in the future.
3) **Long-term indirect internal exposure**: caused by intake of animals or fish and shellfish exposed to radioactive materials emitted from the Fukushima Daiichi Nuclear Power Plant or animals that consumed them through the food chain then being consumed by humans.

Of these 1) indicates the exposure that has already taken place. Focusing on how the exposure in 2) and 3) could possibly take place leads to the routes as viewed in Figure 4.

As shown in Table 2 the routes of particular importance differ depending on the area and period. In assessing the exposure doses the exposure sources can be classified as follows with regard to the issues involved in the respective sources.

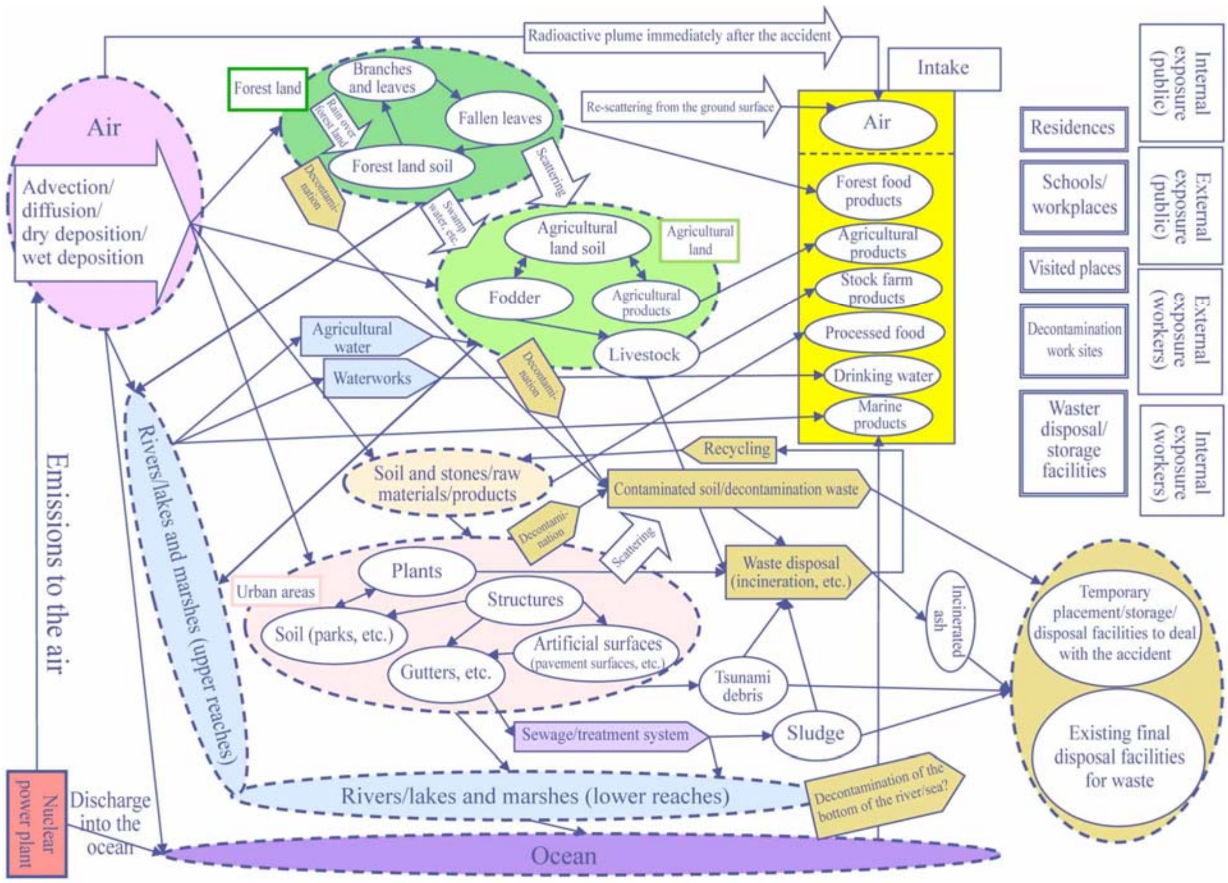

Figure 4　Overview of matters that can pose future health effects to humans

[1] Initial passage of the radioactive plume after the accident

Both internal and external exposure can be assumed to have occurred from exposure to rare gases and iodine contained in the radioactive plume immediately after the accident. In addition, external exposure from radioactive materials adhering to skin/clothes, etc. is also possible. Measurement data by nuclear species immediately after the accident is limited, thus making better estimations than rough estimates difficult at present, and even with the results of measuring the radiation dose rates in the air and the results of external exposure dose examinations being used as reference. Estimation of exposure doses could be improved in the future if the situation during the concerned period can be reproduced by subtly combining the limited measurement data immediately after the accident with simulated diffusions and depositions and by clarifying the temporal distribution of the emitted amounts by nuclear species.

[2] Radioactive materials deposited in various areas

As described in (2) of Chapter 4 the radioactive materials emitted due to the accident were transferred through environmental media and then deposited over ground surfaces and structures on ground surface, forests, agricultural land, and the bottom of rivers, etc. Any people living in these environments could receive external exposure through them. With the estimation of exposure doses made in Chapter 5 the representative values were set based on the measurement results of radiation doses in the air available to date. The environmental dynamics by area of (2) of Chapter 4 being subtly reproduced/predicted, however, would result in estimations using models being considered also possible.

Estimating the medium- to long-term external exposure doses requires the shielding effects when time is spent indoors to be taken into account in many cases. The indoor radiation dose rate in the air, however, may not be all that lower than that of outdoors due to the deposition of radioactive materials on roofs, etc. Verification is therefore considered necessary with estimation based on the outdoor radiation dose rates in the air. In addition, the contribution of re-scattering to internal exposure has been considered relatively small, but verification through continued measurements is expected to take place.

[3] Intake of food and drink

Radioactive materials are contained in agricultural products, stock farm products, forest products, and marine products through direct adhesion of radioactive materials emitted into the environment, transfer from soil, intake of water or fodder, and the food chain, with the intake of those products then causing internal exposure. In predicting the future situation with exposure through food and drink understanding the dynamics of radioactive materials in the environment, as described in (2) of Chapter 4, is considered important.

[4] Artificial transfer of radioactive materials after the accident

Radioactive materials have been artificially transferred through the distribution of goods, including the use of construction raw materials, including macadam and cement, etc., use of wood as firewood, collection/treatment/disposition of waste, and transportation/temporary placing/storage of contaminated soil, etc. In addition to the external exposure of the residents in transferred areas the exposure of workers engaged in these processes is also possible. Regulations for decontamination and waste treatment to deal with the accident of concern (so-called Ionizing Radiation Ordinance for Decontamination[22]) are being provided.

[22] The official title is the “Ordinance on Prevention of Ionizing Radiation Danger with the Decontamination of Soil, etc. Contaminated by Radioactive Materials Produced as a Result of the Great East Japan Earthquake

5 Estimation of exposure doses and prediction of health effects

(1) Estimation of exposure doses

[1] Estimation of external exposure based on radiation dose rates in the air and residential time scenarios

The external exposure doses immediately after (within three days of the accident), over the short-term (three days to three months), medium-term (three months to three years), and long-term (three years to 30 years) were estimated by setting representative values for the radiation dose rates in the air based on "[1] Definition of time base" and "[2] Definition of area classification" in (2) of Chapter 2 and using modeling data as reference values. The medium-term exposure dose was assumed to be from ^{134}Cs and ^{137}Cs, and hence the theoretical decline in the radiation dose rate based on their half-life was taken into consideration. In addition, the following scenarios, which set the declines in radiation dose rates through decontamination measures three years after the accident occurred for each of the classifications provided for in the Act on Special Measures concerning the Handling of Contamination by Radioactive Materials (enacted on August 30, 2011) and assume continuous decontamination measures being used for a certain period after people return if the decontamination level at the time they return from evacuation is insufficient, were used (Tables 3 and 5).

Scenarios used

Zone A: a zone with an additional annual exposure dose before decontamination of around 50 milisieverts (hereinafter sievert is referred to as Sv† and milisievert mSv)

1a) No decontamination after returning at 20 mSv/y

1b) Annual decontamination of 20% constantly for 20 years after returning at 20 mSv/y

2a) No decontamination after returning at 10 mSv/y

2b) Annual decontamination of 10% constantly for 5 years after returning at 10 mSv/y

Zone B: A zone with an additional annual exposure dose before decontamination of around 20 mSv

1a) Evacuation after 3 months at residence, but no decontamination after returning at 10 mSv/y

1b) Evacuation after 3 months at residence, and an annual decontamination of 20%

Disaster". The abbreviated title was used because of the fact that the conventional Ordinance on Prevention of Ionizing Radiation Dangers has been called the "Ionizing Radiation Ordinance". This Ordinance was newly provided to prevent workers engaged in decontamination work, etc. under the Act on Special Measures concerning the Handling of Contamination by Radioactive Materials and other workers from being exposed to ionizing radiation to the fullest extent possible.

constantly for 5 years after returning at 10 mSv/y

2) Evacuation after 1 month at residence, but no decontamination after returning at 5 mSv/y

Zone C: A zone with an additional annual exposure dose before decontamination of around 5 mSv

50% reduction in radiation dose as of March 2014 from September 2011 (5 mSv/y), including the effects of decomposition

Zone D: A zone with an additional annual exposure dose before decontamination of around 2 mSv

50% reduction in radiation dose as of March 2014 from September 2011 (2 mSv/y), including the effects of decomposition

Zone E: A zone with an additional annual exposure dose before decontamination of around 2 mSv, no decontamination

This estimation is for use in surveying the level of contribution to the long-term cumulative exposure dose at various locations with differing radiation dose rates, periods, and durations, and is not precise enough to estimate accurate exposure doses. In addition, rather extreme scenarios were used in order to clearly identify the difference in the contribution ratio.

With zone A, for example, the contribution level of cumulative exposure dose after returning is large with the scenario where it is assumed that some residents will return even at 20 mSv/y and in cases where decontamination to a level of 10 mSv/y is difficult. Achieving a cumulative exposure dose of 100 mSv or less will require continuous decontamination measures after returning. With Zone B the period during which residents could remain within zones with high radiation dose rates until evacuation was set to be one month and three months, but the decontamination level of 10 mSv/y or 5 mSv/y at the time of they returned had a higher contribution level to the cumulative exposure dose.

With every zone the contribution level of medium- to long-term continued exposure was higher than that of short-term exposure during the period of a high radiation dose immediately after the accident. However, this concerns a estimation of external exposure that was based on the measured results of radiation dose rates in the air only, and, as described in (1) [2] b. of Chapter 5 (page 207), the exposure immediately after the accident needs separate consideration.

The half-life of ^{134}Cs is significantly shorter at approximately two years than that of ^{137}Cs at approximately 30 years and the radiation dose per 1Bq is stronger with ^{134}Cs, thus the decay of ^{134}Cs can significantly affect the reduction in radiation dose from the initial stage. However, the other side to that is that the reduction in radiation dose after returning following decontamination is slower than the reduction from immediately after the accident. Care must therefore be taken that the long-term cumulative radiation dose in regions with the same exposure dose rate of 10 mSv/y can differ by the ratio of 1:2 between regions with that of 10 mSv/y one year after the accident and regions with that of 10 mSv/y at the time of returning (three years after the accident).

An assessment of health effects from the exposure doses in the respective scenarios is given in (2) of Chapter 5.

Table 3 Radiation dose rate in the air assumed when estimating the exposure dose

	Peak immediately after the accident	3 weeks after the accident	3 months after the accident	Evacuation area	Current situation as of September 2011		After decontamination (assumed to be March 2014)
	μSv/h	μSv/h	μSv/h	μSv/h	μSv/h	mSv/year	mSv/year
Zone A	50			0.6	10	52.6	10～20
Zone B	50	25	15	0.6	4	21.0	5～10
Zone C	20	5	2		1	5.3	2.6
Zone D	1	0.6	0.5		0.4	2.1	1.1
Zone E	1	0.2	0.18		0.15	0.8	No decontamination

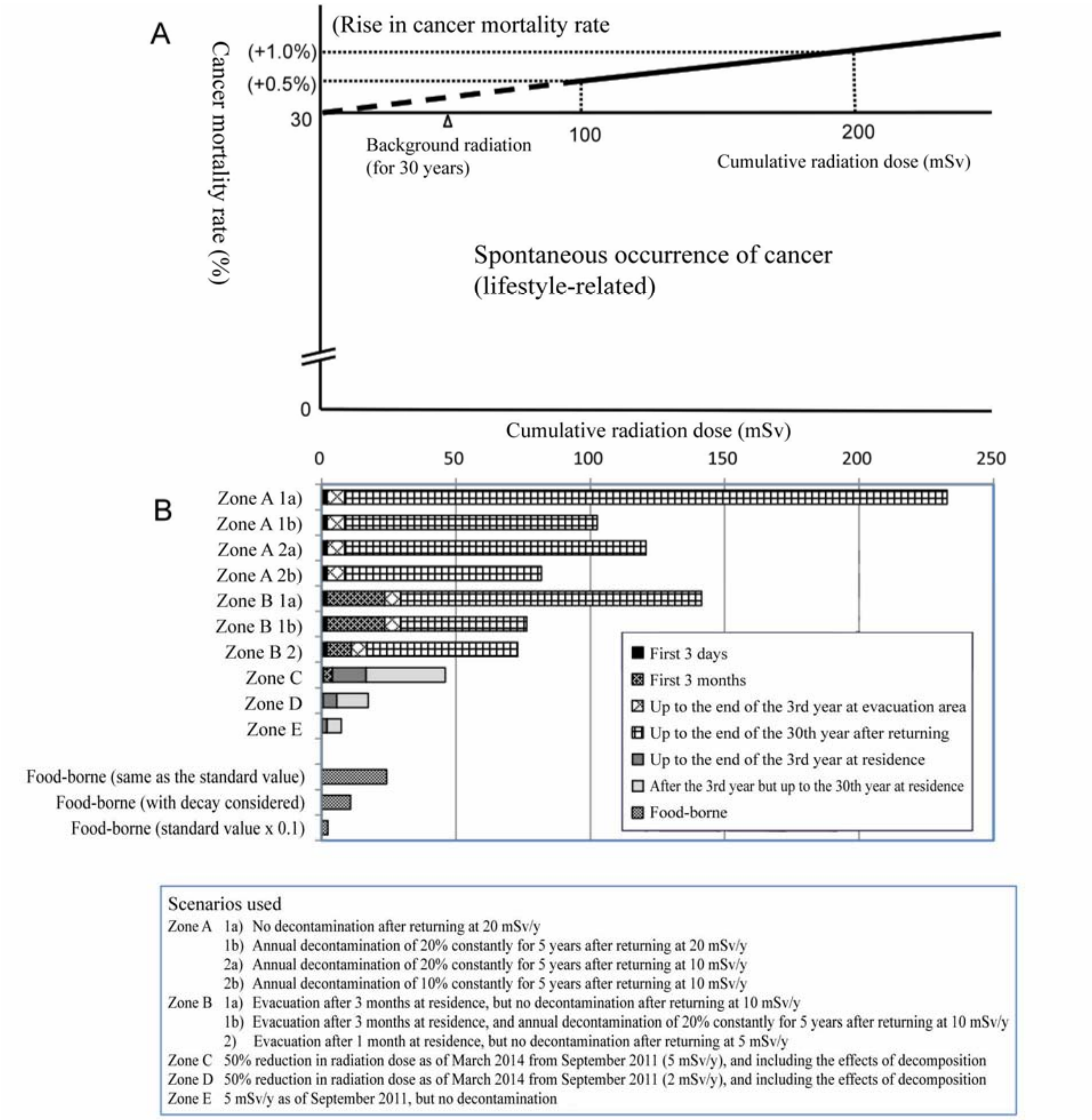

Figure 5 (A) Cancer mortality rate, and

(B) Estimation of cumulative radiation doses over the next 30 years by zone

Note) Food-borne radiation was estimated using extreme scenarios and assuming that the radiation levels in all the food consumed would barely meet the standard values.

[2] Matters of concern with direct exposure other than external exposure scenarios

a. Estimation of contribution level of xenon (^{133}Xe) at the time of the radioactive plume passage immediately after the accident

^{133}Xe accounted for the highest amount of the estimated emitted amount in units of Bq, and with ^{133}Xe having been the main contributor to the sharp rise in the radiation dose rate in the air according to data measured as of March 15, 2011 at the Japan Chemical Analysis Center in Chiba City <1>. In this location, and where the radiation dose rate was around 0.5 μSv/h during the peak period, the average concentration in the air during the period of March 14-22 was reported to be 1,300 Bq/m^3, thus indicating the possibility that the concentration rose two digits higher during the peak period of March 15. Comparison of the radiation dose rate in the air between regions reveals the rate to be three digits higher in the Planned Evacuation Zone than in Chiba City. However, the measurement data by nuclear species was not available, thus making the assessment in these regions rather difficult. With ^{133}Xe, however, the contribution of exposure from outside the body is larger than exposure through air inhaled into the lungs, thus assessing its internal exposure is considered to be in low in the level of requirements. A radiation dose of around 300 μSv/h was observed in Namie town, Fukushima Prefecture on March 15. If exposed to this for three consecutive days the exposure dose would be around 20 mSv.

b. Internal exposure to iodine at an early stage after the accident

For the period of around one week to one month after the accident the contribution of ^{131}I to internal and external exposure was considered to be relatively large, although measured data on the iodine concentration and contribution of iodine to the radiation dose rate in the air at that time is insufficient. Assessment by region requires high spatial resolution simulations. In addition, data on checkups for thyroid exposure and whole-body exposure dose measurements using Whole Body Counters (hereinafter referred to as WBC[†]) conducted immediately after the accident on residents in regions with high radiation dose is considered be in need of careful examination. The exposure dose of the specific organ of the thyroid (equivalent dose) and the effective dose used for the whole body need to be distinguished between and appropriately used.

[3] Food- and drink-borne internal exposure

Provisional standards were established for food and drinking water after the accident. Here, after considering the half-life and physical properties of each of the nuclear species, the subject used in estimating medium- to long-term exposure was limited to cesium in food. Provisional standards were initially set to 500 Bq/kg and new standards from April 2012 to 100 Bq/kg, which is equivalent to 1 mSv annually (the amount in drinking water needs to be deducted to be more precise, but was not considered here for the sake of simplification). The results of inspections approximately one year after the accident revealed the amount of 100-500 Bq/kg to be detectable in quite a few cases, but the amount of actual intake is smaller than the standard values according to the results of inspection of a person's entire diet using a duplicate diet method[23] and the results of measurement by WBC. The situation where the radiation levels of all the food taken by an individual would barely meet the standard values would be very unlikely to occur, but the estimation was made using extreme scenarios here for a comparison with the external exposure doses shown in "[1] Estimation of external exposure based on the radiation dose rate in the air and residential time scenarios" in (1) of Chapter 5.

By setting the same period as for the estimation of the external exposure of 30 years the cumulative committed effective dose for the case of the intake of food that barely meets the standard values based on 1 mSv/y would be 30 mSv (approximately 24 mSv when the ratio between ^{134}Cs and ^{137}Cs is considered). In contrast, and as described above, ^{134}Cs, whose half-life is approximately two years, decays at a relatively early stage. The exposure dose through agricultural products is therefore expected to decrease, even when agricultural products are produced on the same agricultural land with the transfer of ^{134}Cs to agricultural products being constant and at the same rate. After taking into consideration the difference in the scale factor for the committed effective dose of ^{134}Cs and ^{137}Cs the initial dose of 100 Bq/kg would have dropped to approximately 21 Bq/kg in 30 years' time and the cumulative committed effective dose over 30 years would be approximately 10.8 mSv. Assuming that the contamination level of marine products would be retained due to the transfer of cesium from the land to the ocean, as described in (2) [4] of Chapter 4, and the percentage of marine products to all food intake was 10%, which is higher than the actual value, the cumulative dose would be 12.2 mSv.

These values are shown in Figure 5 for comparison against the external exposure dose calculated in "[1] Estimation of external exposure based on the radiation dose rate in the air and residential time scenarios" in (1) of this chapter. After taking into consideration

[23] According to the "Food Safety Glossary (4th edition)" (October 2008) prepared by the Food Safety Commission a method of analyzing a person's overall diet and thus measuring their total amount of intake of the food additives and pesticides contained in their daily diet and using the same diet that a survey subject took as the diet sample. This enables estimation of the amount of intake of food-borne chemical substances taken by the survey subjects. Typically a family that participates in the survey is requested to prepare an extra meal which is then used as the sample.

the decline in radiation dose due to decay the internal dose would be below the external exposure dose in Zones A to D but would exceed the external exposure dose in Zone E. Using the assumption that agricultural land used for growing plants would increase as a result of decay and agricultural products supplied that barely meet the standard values the internal exposure dose would also be exceeded in Zone D. Food is distributed nationwide and hence this estimation generally also applies to Zone F (a zone where external exposure to fallen radioactive materials due to the accident can be ignored).

[4] Exposure of workers related to decontamination work and waste treatment

At decontamination sites, especially when engaging in decontamination at locations where radioactive materials are likely to be concentrated such as gutters, etc., workers are at risk of being exposed to radiation doses that are one digit higher than the radiation dose in the air in the surroundings, although only temporarily. The actual exposure dose is considered to largely depend on the duration of the work, situation with contact with contaminated soil and mud, etc., with a quantitative estimation being difficult at present. In accordance with the Ionizing Radiation Ordinance for Decontamination the maximum exposure dose applicable to workers is 100 mSv over five years, which far exceeds the exposure dose of the residents in Zone A calculated in (1) [1] of this chapter. The effect of the residents' participation in decontamination work to the cumulative exposure dose is considered to be small as long as the duration of that work is short. In the case of engaging in the work for a long duration as volunteers, the actual situation with the level of exposure dose needs to be identified.

(2) Assessment of health effects due to exposure

With regard to health effects due to radiation a high radiation level of 1 gray (hereinafter referred to as Gy†) or higher can cause direct disorders to various systems of the human body when exposed to it at one time. A threshold dose is considered to exist for each disorder with regard to its occurrence. Disorders with a threshold dose of 1 Gy or lower include temporary infertility in males at 0.1 Gy and hypofunction of the hematopoietic system at 0.5 Gy <18>.

In contrast to this, however, exposure to relatively low radiation doses can also damage genes, with errors that arise when repairing the damage being known to cause gene mutations or chromosomal abnormalities, thus raising the risk of cancer. With regard to cancer due to radiation the mortality risk increases in proportion with doses of 100 mSv or higher. No scientific evidence exists that the mortality risk increases in proportion with the low radiation dose of 100 mSv or lower. From the standpoint of radiation protection, however, the mortality risk should be assumed to increase in proportion with radiation doses of 100 mSv or lower and the cancer mortality rate estimated to be 5×10^{-2}/Sv, as based on epidemiologic studies of atomic bomb survivors of Hiroshima/Nagasaki <18>. Figure 5 A shows the above description in a schematic manner. Considering that the life-style related spontaneous cancer mortality rate of Japanese people is 30% increase in the cancer mortality rate due to radiation of 100 mSv or lower is rather small.

With regard to the effects of the accident on the residents and according to the external exposure dose estimation results in the basic survey of Fukushima Prefecture's "Prefectural People's Health Management Survey" conducted in the precedence survey areas (Kawamata town (Yamakiya region), Namie town, and Iitate village) an effective radiation dose of over 10 mSv was observed in 71 of 9,747 residents, with the highest dose being 23 mSv. The Committee for the Fukushima Prefecture "Prefectural People's Health Management Survey" evaluated that health effects due to radiation to be unlikely (announced on March 20, 2012) <19>.

167 workers working to restore the situation after the accident were exposed to effective radiation doses of over 100 mSv (as of the end of January 2012) <20>. In addition, some workers were exposed to high internal doses, although mainly due to the intake of radioactive iodine (the maximum committed effective dose was 590 mSv). No health effects have been observed in the health checkups of those workers to date.

Simply contrasting the effective radiation dose with the increased risk is not considered advisable <18>. The horizontal axes of Figure 5 A and B use the same scale in helping to understand the outline of health effects due to an exposure dose estimated over 30 years in the respective scenarios. In addition, the Δ on the horizontal axis of Figure 5 A indicates the cumulative expose dose over 30 years at approximately 1.5 mSv per year, and which is equivalent to the dose that Japanese people are deemed to be exposed to from background radiation. This reveals the additional exposure dose due to the intake of food with the concentration of the standard values for 30 years to be smaller than the exposure dose from background radiation.

6 Recommendations

The Sub-Committee estimated the health effects due to Fukushima Daiichi Nuclear Power Plant accident based on currently available reliable data. Reliability assessment of the results of integrating the results of multiple studies on emissions through to health effect assessment conducted by the Sub-Committee, however, requires that reliability information on the results of the measurements/estimations used as the base figures (hereinafter referred to as uncertainty information) be disclosed, but in actuality this information was not provided in many cases.

However, provisional estimations, although based on the limited data and information available at present, also suggested the importance of appropriate management of cumulative radiation doses in thereby accurately identifying future health conditions.

Based on the exposure doses discussed and health effects estimated for the different exposure routes the following six recommendations are provided here for use in minimizing health effects and improving the future assessment of health effects due to radiation exposure.

(1) Alleviation of effect on public health resulting from the Fukushima Daiichi Nuclear Power Plant accident

The following three recommendations to the relevant government/municipalities/academic circles were made in order to alleviate effect to public health resulting from the Fukushima Daiichi Nuclear Power Plant accident.

Recommendation 1:

The government/municipalities shall, in cooperation with academic circles, continue to improve the precision of the estimated exposure doses immediately after the accident and implement those estimated cumulative exposure doses in protecting the health of those already exposed to radiation, and children and infants in particular. In addition, and with regard to the medical checkups/examinations of residents being continuously implemented by the government/municipalities, a system that can be used to provide thyroid ultrasound examinations and blood tests shall be established with the installation of appropriately calibrated whole body counters. A regional medical system that enables residents to receive appropriate and prompt treatment in the case of health abnormalities being detected shall also be established. The government/municipalities shall establish a system that enables residents to maintain good health not only by reducing future radiation exposure to the fullest extent possible but also via thorough implementation of health management, and concerning cancer factors other than radiation exposure.

Recommendation 2:

The government/municipalities shall implement appropriate measures such as the establishment of decontamination targets, including the post-return of residents and management of decontamination work, etc., in order to prevent cumulative exposure doses from reaching a level that could pose a negative health effect because of potential further exposure due to their return/decontamination work.

Recommendation 3:

Academic circles in Japan shall plan appropriate basic biological/medical research and epidemiological research for use in estimating a low radiation dose-response curve for the carcinogenic rate and cancer mortality rate, implement it in cooperation with the government/municipalities, identify the actual situation with the health effects of low radiation doses through integration of the findings thereby obtained, and promptly reflect the measures derived in the health management of the residents.

(2) Assessment of the present situation with and future of damage caused by radiation and more accurate estimation of health effects

The following three recommendations were made regarding an assessment of the present situation with and future of damage caused by radiation and more accurate estimation of health effects.

Recommendation 4:

The government and academic circles in Japan will be requested to cooperate in establishing a cross-disciplinary research system for use in identifying the overall picture related to the assessment of radioactive health effects, as shown with the approach used in these recommendations, more accurately identifying the actual situation with radiation contamination and health effects associated with the Fukushima Daiichi Nuclear Power Plant accident, and appropriate selection/implementation of decontamination and health effect prevention measures.

Recommendation 5:

In order to facilitate assessments/research that contribute to the assessment of health effects the government shall establish a system that enables a prompt and steady collection of the data required in examining the accident, data that significantly affects estimation accuracy when estimating health effects, and data that can be used as evidence to determine policies that prevent any damage from the health effects, and an integrated system that provides data in the form that allows researchers to use/analyze it. In addition, a system that enables academic circles to verify the validity/reliability of the provided data is also necessary. Establishing this type of system is desirable not only for this accident but also for use as a system that contributes to the reduction of the disaster/accident damage that could possibly affect the lives of the people.

Recommendation 6:

Institutions/researchers engaged in radiation-related measurements or model-based estimations are expected to disclose the results of the various measurements/estimations that will be used as base figures in assessing radioactive health effects together with uncertainty information. In addition, accuracy control or improvement of the measurements/estimated results based on uncertainty information needs to be planned and implemented.

7 Future issues

In addition to the six recommendations given in Chapter 6 five issues still need to be resolved by academic circles, in particular, and are as described below.

(1) Improvement of modeling and data analysis technologies in relation to emission/diffusion/ exposure/health effects

Improvement of the precision of atmospheric/oceanic diffusion simulations conducted in cooperation with researchers in various fields needs to be continued in the future. Improved simulations are needed, for example more precise numerical models and improved technologies, in thereby covering for any missing emission source information and modeling data through data analysis, including inverse estimations and data assimilation, etc. However, thorough understanding of the deposition/transfer of radioactive materials scattered over wide areas, exposure routes, and health effects will require cooperation between the fields of radiation protection and earth sciences.

(2) Reinforcement of academic reasoning related to assessment of radioactive health effects and the approach

With regard to the effects of low radiation doses a very large amount of scientific literature has been reviewed by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and U.S. Committee on the Biological Effects of Ionizing Radiations (BEIR). Based on the studies, which cover various point of views, including radiation dose-response relationships, doses and dose-rate effectiveness, and existence of threshold values, etc., the International Commission on Radiological Protection (hereinafter referred to as ICRP) assumed application of a linear no-threshold model (hereinafter referred to as the LNT model) as the tool to be used in risk management and regulation on the basis of the concept of radiation protection. ICRP recommendations <18> based on this approach have been broadly and internationally accepted and incorporated into radiation safety related laws and regulations in countries all over the world.

The frequency of cancer due to low dose radiation is far lower than the spontaneous occurrence of cancer, and thus significant uncertainty can be observed in the results of epidemiologic studies, and with no sufficient scientific evidence existing that enabled verification of the LNT model itself. Large-scale comprehensive research thus needs to promptly take place. The risk of cancer with children in particular is of high public interest and also a cause of public anxiety, thus leading to risk assessment research, etc. being expected to take place.

An epidemiologic study on the atomic bomb survivors of Hiroshima/Nagasaki was based on a long observation period with various statistical analysis methods being used. Thorough analysis through this study is therefore expected to result in data from the existing large population.

Furthermore, clarifying the mechanism via biological studies as evidence to cover the statistical uncertainties in epidemiologic studies is also a future issue. Molecular biological studies on gene damage from low radiation dose exposure have been conducted for a number of years now. Recent progress in biotechnologies, however, provides new research methods that enable studies on gene damage from low dose radiation from a molecular biological point of view.

(3) A transition from countermeasures/standards setting at an early stage based on a precautionary principle to the setting of medium- to long-term countermeasures/standards based on academic reasoning and cost-benefit analysis

Effects of radiation emitted into environment not only last a long time but also cannot be artificially eliminated. Furthermore, scientific knowledge on long-term effects of low dose radiation on the human body is still insufficient.

Using the assuming that radiation would have some unrecoverable effects on the human body the government set radiation control zones and implemented measures in accordance with the "precautionary principle[†]", including thorough control of radioactive materials, etc. In fact the forced evacuations and decontamination with regard to human residences, being in accordance with the level of radiation dose rate in the air and effects on the human body, and food inspections with regard to internal exposure, have been implemented in accordance with the precautionary principle.

However, the process and evidence of political decision making in setting these standards was unclear, thus leading to public distrust. With regard to the way political decisions are made, it was once again clarified after the accident that no scientific discussions or examinations had taken place on the evidence which should rationally be used to make political decisions when scientific causal relationships and facts cannot be clearly identified. There still remain many important issues with effectively referable precedents rarely available throughout human history, including the return of the residents that are owners of land in regions with significant radioactive material depositions, etc. The ideal political decision making process that takes human values into consideration in cost-benefit analysis with these issues needs to be discussed across the fields of humanities and science and within academic circles.

(4) Strengthening of risk communication between academic circles and society

The issue raised here is an extremely important issue for scientists: how to provide risk information that is based on scientific knowledge and its assessments to society. Discussions have been inadequate on exactly how scientists should provide information in cases where many people are worried because no explanation was available in an understandable manner, and on what kind of risk exists, but the fact is that the risk was yet to have been sufficiently verified scientifically at that point. In addition, and because the scope and definition of objective "scientific facts" were unclear, the scientific facts and scientific impact assessment of facts based on the assumption of future aspects got mixed up, and assessments with large uncertainties in the point of concerns were reported as facts. Information on appropriate scientific data collection methods in particular was inadequate, and the difficulty in accurately predicting the effects on human body increased confusion via that information provision.

In consideration of that situation sufficient discussions will need to take place in the future on exactly how information can be appropriately provided at a point when a clear conclusion can scientifically be reached.

Furthermore, training of personnel to engage in radiation education and radiation related work needs to be carried out as a part of risk communication and in thereby educating and reinforcing medical professionals (doctors, nurses, public health nurses, maternity nurses, pharmacists, and veterinarians, etc.) is a future issue.

(5) Limitations of recommendations

Lastly, the limitations of these recommendations also need to be clarified. The Sub-Committee made the effort to collect and compile existing data to the fullest extent possible, but quite a few documents could not be accessed.

Information on the assessments of the exposure dose and health effects on those working to restore the situation after the accident at the Fukushima Daiichi Nuclear Power Plant in particular was not made sufficiently available to the Sub-Committee. SCJ issued a recommendation on the "Integrated Management of Exposure of Radiation Workers" on July 1, 2010 to point out the necessity for the integrated management of the radiation exposure of radiation workers, including revision of all the relevant laws and regulations. SCJ should include this when they proceed with discussions of this issue.

In addition, the effects of radiation on the human body are composite, and the contribution ratio can roughly be estimated scientifically, but it is only a stochastic estimation. Actual effects on individuals cannot be scientifically clarified with the approach used here. SCJ compiled these recommendations while fully aware of these limitations.

<Definition of terms>

Exposure (internal exposure and external exposure)

Exposure of organisms to radiation. Internal exposure refers to exposure to radiation emitted by radioactive nuclear species that exist inside the body while external exposure refers to exposure to radiation emitted by radioactive sources outside the body. The effects of both external exposure and internal exposure can be added to assessments.

Nuclear species (radioactive nuclear species)

An atomic nucleus consists of protons and neutrons. A specific number of protons and neutrons distinguishes the atomic nucleus. A nuclear species is an atomic nucleus with a specific number of protons and neutrons. There are two types of nuclear species: stable nuclear species and unstable nuclear species in which the number of number of protons and neutrons changes as a result of alpha or beta decay. Radioactive nuclear species refers to nuclear species that causes these types of decay. Gamma decay usually takes place over a very short time and the number of protons and neutrons do not change. Some nuclear species gradually emit gamma rays (called gamma decay from a metastable state), however, and nuclear species while in this metastable state are also referred to as radioactive nuclear species.

Half-life

Radioactive nuclear species involve alpha or beta decay, upon which they are transformed into a different type of nuclear species. Gamma decay does not change the number of protons and neutrons but the energy in the metastable state changes and conversion to a state of less energy takes place. The initial number of nuclear species therefore decreases with time. Half-life refers to the time taken for the initial number of nuclear species to decrease to half.

Radioactive plume

Plume refers to a cloud-like substance that come outs of chimneys like smoke. When radioactive materials are emitted due to the explosion of atomic bombs or nuclear power plant accidents a mass of gas containing radioactive materials flows out, and is like a thread of smoke. Radioactive plume refers to this type of mass of gas containing radioactive materials.

Radiation dose (high, low, in the air, threshold, equivalent, effective, and committed effective)

An index used to indicate the amount of energy of radiation absorbed by a substance per unit mass. The radiation absorbed dose is used to indicate the energy absorbed per 1kg of substance (J: joule), the equivalent dose is calculated by multiplying the radiation absorbed dose of organs/tissues by a radiation weight factor that takes into consideration the level of effects of different types of radiation, and the effective dose is calculated by adding up the results of multiplying each equivalent dose by a tissue weight factor that takes into consideration the difference in radiation sensitivity of organs/tissues. In the case of internal exposure an assessment is made based on the energy absorbed by each organ over 50 years with adults and for the period until they reach age 70 with children, and this is thus called the committed effective dose. A unit called ambient dose equivalent is used when monitoring air.

Unit (becquerel (Bq), sievert (Sv), and gray (Gy))

A unit used with radiation is Bq (becquerel). 1 Bq means that radiation is emitted as a result of nuclear species decaying once every second. A unit used for the radiation absorbed dose is J/kg, and Gy (gray) is used as a special name (1 J/kg = 1Gy). The unit used for the equivalent dose and effective dose is Sv (sievert).

WSPEEDI-II

A simulation system introduced by the Japan Atomic Energy Agency in 2009 for use in estimating air diffusion and emitted points of radioactive materials in case of the abnormal emission of radioactive materials due to a nuclear facility accident. WSPEEDI-II refers to the second edition of the Worldwide version of System for Prediction of Environmental Emergency Dose Information that was developed in 1997.

Whole Body Counter (WBC)

Equipment to measure gamma-rays emitted from radioactive nuclear species inside the whole body using a detector outside the body. Alpha-rays and beta-rays have weak penetration and are therefore not measurable outside the body. Multiple types of WBCs exist, including a shield type, which masks the radiation outside by completely covering the measuring equipment, and an open type. Only radioactive nuclear species existing inside the body at the time of measurement can be measured. Estimating internal radiation exposure doses therefore requires nuclear species intake scenarios or calculation models.

Precautionary principle

A principle that where there are threats of serious or irreversible damage a lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation and which was agreed upon at the Rio Declaration at the

United Nations Conference on Environment and Development in 1992. Although no internationally agreed strict definition exists, COMEST (World Commission on the Ethics of Scientific Knowledge and Technology) of UNESCO, for example, published "The Precautionary Principle" in March 2005 and proposed the following definition as a solid base for discussions: "When human activities may lead to morally unacceptable harm that is scientifically plausible but uncertain actions should be taken to avoid or diminish that harm. Morally unacceptable harm refers to harm to humans or the environment that is threatening to human life or their health, or serious and effectively irreversible, or inequitable to present or future generations, or imposed without adequate consideration of the human rights of those affected. " This proposal recommended that the judgment of plausibility should be grounded in scientific analysis and analysis should be ongoing so that chosen actions are subject to review. It also stated that uncertainty may apply to, but need not be limited to, causality or the bounds of the possible harm. The proposal further stated that "Actions are interventions that are undertaken before harm occurs that seek to avoid or diminish the harm. Actions should be chosen that are proportional to the seriousness of the potential harm, with consideration of their positive and negative consequences, and with an assessment of the moral implications of both action and inaction. The choice of action should be the result of a participatory process."

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<Background Information 1> Progress of deliberations of the Sub-committee on Counter-measures for Radiation, Committee on Supporting Reconstruction after the Great East Japan Earthquake

2011

November 16 Executive Committee (140th) of SCJ

Establishment of the Sub-committee on Counter-measures for Radiation Contamination, Committee on Supporting Reconstruction after the Great East Japan Earthquake and its members decided

December 8 Sub-committee on Counter-measures for Radiation Contamination (1st)

○ Basic ideas, information sources of radiation contamination and exposure, etc.

December 28 Sub-committee on Counter-measures for Radiation Contamination (2nd)

○ Overall perspective, data map (1st draft), data sources, etc.

2012

January 8 Executive meeting of the Sub-committee on Counter-measures for Radiation Contamination (1st)

○ Main ideas of the draft recommendations, etc.

January 16 Sub-committee on Counter-measures for Radiation Contamination (3rd)

○ Simulation model, health effects due to radiation, future deliberations, etc.

January 19/20 Field survey in Fukushima City, Mianamisoma City, and Soma City, Fukushima Prefecture by the Sub-committee on Counter-measures for Radiation Contamination

February 12 Executive meeting of the Sub-committee on Counter-measures for Radiation Contamination (2nd)

○ Main ideas of the draft recommendations, etc.

February 17 Sub-committee on Counter-measures for Radiation Contamination (4th)

○ Future deliberations, etc.

March 7 Sub-committee on Counter-measures for Radiation Contamination (5th)

○ Draft recommendations

March 16 Committee on Supporting Reconstruction after the Great East Japan Earthquake (3rd)

○ Approval of a proposal to change the title of the Sub-committee on Counter-measures for Radiation Contamination to "Sub-committee on Counter-measures for Radiation"

○ Report and deliberations of (proposed) Recommendations by the Sub-committee on Counter-measures for Radiation

March 26 – April 1

Call for opinions on (proposed) Recommendations by the Sub-committee on Counter-measures for Radiation from Council Members and Members

April 3 Committee on Supporting Reconstruction after the Great East Japan Earthquake (4th)

Report and deliberations on (proposed) Recommendations by the Sub-committee on Counter-measures for Radiation "A New Step towards Counter-measures for Radiation – Towards Science-based Policy Action –"

The following <Background Information 2> and <Background Information 3> were edits of material prepared in cooperation between the members of the Sub-Committee and experts in the course of compiling these recommendations. The recommendations were compiled by selecting parts of the abovementioned material and then summarizing them.

<Background Information 2> Supplementary information to "(1) Estimation of emitted amounts" of Chapter 4

1) Abundance of nuclear materials at Nuclear Power Units 1-4 before the accident

Stohl et al. <1> estimated the nuclear fuels inside the nuclear reactors of Units 1-3 of the Fukushima Daiichi Nuclear Power Plant that emitted radioactive materials and the spent fuel in Unit 4 with possible emissions based on the number of spent fuel rods and ORIGEN code <2> that the abundance of cesium 137 before the accidents in the nuclear reactors of Units 1-3 was 2.4×10^{17} Bq, 3.5×10^{17} Bq, and 3.5×10^{17}Bq, respectively, or a total of 9.4×10^{17}Bq, and that of the spent fuel in Unit 4 was 1.1×10^{18}Bq (or a total of 2.2×10^{18}Bq in Units 1-4).

2) Uncertainty of estimation based on the results of analyzing the state of the nuclear reactors

The emitted amount, as estimated based on the results of the state of the nuclear reactors having been analyzed by the Nuclear and Industrial Safety Agency and the assistance of the Japan Nuclear Energy Safety Organization using the severe accident analysis code MELCOR (Methods for Estimation of Leakages of Release), lacks observations of the temperature inside the nuclear reactors and their damage status. According to the Nuclear Emergency Response Headquarters report, which made use of "sensitivity analysis" in examining the level of changes in the results of the estimations by changing various parameters, however, the minimum and maximum values of the estimated emission rate of iodine and cesium from Unit 2 in that sensitivity analysis differs by approximately 20 times <3>. Significant uncertainty therefore exists in the estimated total emitted amount using this method (iodine 131: $0.3\text{-}8\times10^{17}$ Bq, cesium 134: $0.4\text{-}9\times10^{16}$Bq, cesium 137: $0.3\text{-}8\times10^{16}$Bq), and hence other estimation methods are necessary in reducing that uncertainty.

3) Uncertainty of inverse estimation using WSPEEDI-II

The process of the inverse estimation of the emitted amount using WSPEEDI-II can be summarized as follows.

First, the level of diffusion at the monitoring points is estimated using WSPEEDI-II and the unit amount of radioactive materials emitted from the Fukushima Daiichi Nuclear Power Plant. Next, dust sampling or radiation dose rate measurements at the monitoring points takes place for use in then comparing the level of difference with estimated values, and an inverse estimation conducted for the emission rate at the point of the Fukushima Daiichi Nuclear Power Plant. Lastly, the average value of the inversely estimated values was calculated. However, the level of uncertainty of this estimated value is not currently available. In contrast to this Stohl et al. used measured values from remote areas and calculated the estimated emitted amount of cesium 137 to be 3.6×10^{16} Bq, and also reported the estimated value with uncertainty information to be $2.3\text{-}5.0\times10^{16}$ Bq, being based on model application residual error information <1>. In addition, this overseas study also estimated the emitted amount from the nuclear reactors in Units 1-3 and spent fuel in Unit 4. It is characterized by the estimation that the contribution of Unit 4 was larger than Units 1-3. It reported that water injected over the spent fuel in Unit 4 on March 20 was effective as the estimated emitted amount radically decreased immediately after the commencement of the water injection. However, the evidence for large amounts of emissions from Unit 4 was rather poor, and hence the analysis made by Stohl et al. that used this as part of its background information needs further verification.

In contrast to this the inverse estimation made via use of WSPEEDI-II by JAEA used a smaller number of monitoring points in which the measurement error is considered independently when compared to the estimation process used by Stohl et al., and thus the estimated values can be significantly uneven, although small and with small amounts of deviation. In fact Shigekazu Hirao and Hiromi Yamazawa of Nagoya University estimated the amount of radioactive iodine and cesium emitted into the air using environmental monitoring data and a method that is relatively similar to JAEA, and thereby raised awareness of the issue in their report on March 8, 2011 that the uncertainty with this type of inverse estimation needs to be verified <4>.

In a discussion held at the third meeting of the Sub-Committee on Counter-measures for Radiation some of the members commented that model errors in the analysis by Stohl et al. could be larger than the errors in the inverse estimation using WSPEEDI-II, which can better reproduce the diffusion of initial emissions around the Fukushima Daiichi Nuclear Power Plant. In addition, and at a hearing that took place at the fourth meeting of the Sub-Committee on Counter-measures for Radiation, Haruyasu Nagai of the Japan Atomic Energy Agency (JAEA) commented that the estimation made by Stohl et al. and that of JAEA was consistent with after late March, the period during which Stohl et al. argue that the emissions from Unit 4, but which has yet to have been confirmed, significantly decreased. At present the Sub-Committee positions the inverse estimation of JAEA to be the key estimation method. In a discussion at the workshop held on March 8, 2012, the inverse estimation of JAEA, which was mainly based on monitoring points within Fukushima Prefecture, was pointed out to have underestimated the amount of discharge into the ocean, while some of the members also had doubts about the results of Stohl et al. with regard to Cs137 <5>.

With regard to the estimation of the emitted amount into the air many reported the estimated daily emitted amount to be basically the equivalent of its uncertainty value from the beginning of April. Absolute care should be taken that this does not justify ignoring long-term cumulative emissions after the beginning of April. Preferably, the cumulative emission amount needs to be calculated and the uncertainty of the cumulative amount assessed until the temperature of the nuclear fuel inside nuclear rectors reaches a sufficiently low level that physically does not allow any emission of radioactive materials.

4) Discharge of radioactive materials into the ocean

According to documents made available by the Nuclear Emergency Response Headquarters the initial major discharge of high concentration radiation contaminated water into the ocean was estimated to have taken place during April 1-6 through trenches from the turbine building of Unit 2. This is based on a comparison between the concentration of stagnant contaminated water in the underground floor of Units 1-4 and the high concentration contaminated water discharged. The estimated discharged amounts were iodine 131: 2.8×10^{15} Bq, cesium 134: 9.4×10^{14} Bq, and cesium 137: 9.4×10^{14} Bq. In addition to this, and due to the storage of contaminated water, the release of low level contaminated water during April 4-10 and the discharge near the water intake of Unit 3 on May 3 were separately reported <6>. However, these values were estimated based on an observation of the situation with the discharge when the discharge was discovered, and thus the existence of other undetected discharges is unknown. In addition, these estimated discharged amounts are inconsistent with the results of the inverse estimations made by the Japan Meteorological Agency and the Japan Atomic Energy Agency. The results of the inverse estimates, however, are consistent. The results of the Japan Meteorological Agency, which also conducted uncertainty assessment of the estimated values, are therefore being regarded as the key analysis results for the time present.

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[25] *: The original was written in Japanese and SCJ provides informal English translation for non-Japanese readers.

<Background Information 3> Supplementary information to "(2) Diffusion of radioactive materials in land, air, water, and solids" of Chapter 4

Significant work in cooperation with a large number of relevant researchers, including other Sub-Committees, was involved in (2) of Chapter 4 of these recommendations, which had to be largely summarized in the main body of these recommendations. <Background Information 3> presents source materials that could not be described in the main body of the text.

a. Distribution of initial fallout due to air diffusion

Radioactive materials emitted from the source get transported as gaseous materials or particulate materials and eventually deposited over land and sea surfaces through dry deposition (gravity fall and vertical transport due to turbulent flows, etc.) and wet deposition via rainfall. According the results of calculations using some high granularity models 25-37% of cesium 137 emitted as a result of the accident was estimated to have been deposited over Japanese land at a latitude of 32 to 42 degrees north and the remaining portion over other areas, including the ocean (Kawamura et al., 2011; Morino et al., 2011; Ohara/Morino, 2012; Tanaka, 2011; Takigawa, 2012). The diversity is this assessment is due to a difference in the assumption of the scavenging rate due to rainfall, assumption of temporal changes in the emitted amount, and the results of calculating the meteorological fields, thus requiring a comparison be made of the different models for other nuclear species and a reduction in the simulation error in the future.

Radioactive materials emitted into the air formed a high concentration plume that then rode an air current which transported the material to the respective areas of Japanese land (Yasunari et al., 2011; Figure A3-1).

During the day on March 12 southeast winds were predominant around the nuclear power plant. According to the Ministry of Economy, Trade and Industry (2011), from the morning through to the afternoon of March 12 dust was sampled from two points, namely Katase (8:39-8:49) and Kawazoe (12:00-12:10), which are located15 kilometers northwest of the Fukushima Daiichi Nuclear Power Plant. A simulation using those results and WSPEEDI-II (Katata (2012)) estimated that iodine 131 was emitted within the range of 20TBq/hour to 40TBq/hour. Four and a half hours after the hydrogen explosion at 15:30 a radiation dose rate of 20 μGy/h was observed in Mianamisoma City, which is located 24 kilometers North Northwest, but rapidly declined to around 5 μGy/h after the passage of the mass of gas. The deposited amount was therefore estimated to be not very large. However, no dust sampling data from the evening of March 12, when a mass of gas produced by the hydrogen explosion was considered to have passed, has been found to date, and thus the concentration and breakdown of nuclear species within the mass of gas remain unknown.

From midnight of March 12 the direction of the wind in the surrounding areas changed to northwest, with 21 μSv/h having been measured at the Onagawa Nuclear Power Plant at around 1:50 of Mach 13. Dust was sampled at 16 points on March 13, and iodine 131 exceeding the minimum limit of detection detected at Ootabashi (15:08-15:18, 84 Bq/m^3) and Hirusone (16:22-16:32, 100 Bq/m^3), etc. The maximum amount detected in front of the Environmental Radioactivity Monitoring Center of Fukushima was 5.8 Bq/m^3 until 16:00, but which then sharply increased to 60 Bq/m^3 in an observation made at 18:00-18:10, thus radioactive materials were estimated to have been transported inland. Similar to March 12, however, no consistent rise in the radiation dose rate was observed, and thus the rise in the radiation dose rate was considered to have been due to a radiation plume that passed.

A hydrogen explosion took place in Unit 3 before noon of March 14, but no dust sampling data around this time has been found to date. The direction of the wind near the front gate of the nuclear power plant was northerly and no significant increase in the radiation dose rate was observed. The results of modeling revealed the radioactive materials emitted into the air were likely to have been discharged into the ocean. From midnight of March 14 to the dawn of March 15 a significant increase in the radiation dose rate was observed near the front gate of the nuclear power plant, with an extremely high concentration in the air (1260 Bq/m^3) also being measured at 4:25-4:45 on March 15 in dust sampled at Tokai village by the Japan Atomic Energy Agency. A remarkable amount of emissions took place at that time, and radioactive materials crossed the Hamadori region of Fukushima Prefecture to the south via a northerly wind and reached the Kanto Region. They were then estimated to have been transported to the mountainous region in the northeast of the Kanto Region as the wind changed direction due to an approaching low pressure trough in the afternoon and was then deposited through wet deposition via rainfall. In addition, part of the radioactive materials may have been transported to the southern part of Hamadori region and then deposited through wet deposition. The mass of gas caused a high radiation dose rate in various regions, but the radiation dose rate then sharply declined after its passage in many locations, and thus the deposited amount was estimated to be relatively small, although excluding that in the mountainous region in the northeast of the Kanto Region.

Radiation dose observations in the surrounding areas lead to the estimation that another amount of significant emissions took place during the afternoon of March 15. According to an air diffusion simulation using the air-transport model WSPEEDI-II (Katata, 2011), etc., a significant emission from Unit 2 took place during the afternoon of March 15, and radioactive materials then crossed the Abukuma Mountains via a southeast wind and covered the high radiation regions located northwest of the Fukushima Daiichi Nuclear Poser Plant, including Iitate village, etc., and the Nakadori region of Fukushima Prefecture. They were then estimated to have been deposited through wet deposition via a broad front of rainfall as the front passed over from the evening of March 15 to midnight of March 16. However, no sampling data during this period has been found. The radiation dose rate during the afternoon of March 15 and the emitted amount that caused an increase in the deposited amount were therefore estimated based on observations made of the radiation dose rate in the air, and the breakdown of nuclear species, etc. indirectly estimated from the deposited amount, etc. Radioactive materials emitted from the nuclear power plant during the morning of march 16 were temporarily transported to the east into the sea via a northwest seasonal wind, which grew stronger after the passage of a low pressure trough, but the direction of the wind then changed as a small scale cold low passed in the afternoon, and hence a part of the radioactive materials were considered to have been transported to the southern part of the Hamadori region of Fukushima Prefecture.

A plume generated by an emission during the morning of March 20 covered the northern part of the Kanto Region, and an emission in the afternoon resulted in wet deposition via rainfall in the northern part of Miyagi Prefecture and the southern part of Iwate Prefecture, which is considered to have caused rice straw contamination. On the next day, and as the front moved south, the radioactive materials were transported from the southern part of Ibaraki Prefecture to the western part of Chiba Prefecture and the eastern part of Tokyo Metropolis on a northwest wind. At this time, due to an approaching depression, rain fell over the entire Kanto Region and this was considered to have facilitated wet deposition.

As described above the formation of high radiation dose regions that expanded over the respective East Japan regions is considered to have been strongly affected by the wind direction and precipitation field. However, intake into the human body through inhalation takes place when radioactive materials that exist in the air are inhaled. Internal exposure therefore frequently occurs in areas with high concentrations of radioactive materials that can easily be taken into the human body, such as radioactive iodine and cesium, etc., and even without rainfall. The radioactive materials do not remain in the same location for very long because of air transportation, and hence understanding the situation at the time of concern requires observation of the concentration of radioactive materials in the air and observation data on the gamma-ray spectrum at that location. However, most monitoring posts stopped functioning due to the earthquake and a power failure, etc., and those in operation were sustained by standby power sources, thus all the monitoring posts are considered to have ceased operating by around May 15. Understanding the situation will therefore have to be based on a combination of limited observation data and model simulations.

The deposited amount estimated from the results of model calculations and actual measurements are shown in Figure A3-2, and which enables general understanding of the status of the transportation and deposition. Errors of around one digit exist in the deposited amount (Morino et al., 2011; Ohara/Morino, 2012), however, thus requiring more precise calculations in the future.

Observation of the radioactivity concentration in the air has been conducted to be used as base data when discussing the long-term effects of low radiation internal exposure. According to this the radioactivity concentration in the air significantly increased after the accident across wide areas of the southern Tohoku Region and Kanto Region, with measurements made by Fukushima Prefecture and voluntary surveys by researchers revealing the concentration of radioactive cesium to have been 10 to 1,000 times higher (10^{-3}-10^{-5} Bq/m^3) than prior to the accident in Fukushima City, etc., even as of March 2012. The main cause of the increased radioactivity concentration in the air after the accident was the continued leakage of radioactive materials, also in small amounts, from the Fukushima Daiichi Nuclear Power Plant. In addition, a survey made by the Ministry of Education, Culture, Sports, Science and Technology, etc. revealed the contribution of re-scattering from the soil and plants to have also been measurable. Quantification of re-scattering mechanisms and transfer to pollen also needs to be promoted in the future. Furthermore, monitoring needs to be continued as additional scattering/transfer of radioactive materials through future decontamination work, treatment of the debris, and burning off fields is considered possible.

In March 2011, when the accident took place, the weather conditions were such that the winter seasonal wind remained stronger than average. If the northwest seasonal wind were also strong on March 15 most of the large amount of radioactive materials emitted from the nuclear power plant would have been blown over the ocean and thus serious contamination in Fukushima Prefecture avoided. In actuality, however, a strong low pressure trough that just happened to have passed led the wind near the ground surface inland, and also caused rainfall, thereby resulting in serious contamination. In addition, if the weather conditions were such that depressions frequently passed, as they usually do in March an average, an even more serious situation with Japanese land being contaminated by a larger amount of radioactive materials over wider areas would have occurred. An aspect of the transportation/deposition of radioactive materials largely depends on the accidental nature of the timing of the emission and the timing of atmospheric disturbance passages, thus be able to predict the transportation/deposition based on up-to-date numerical prediction data on atmospheric conditions is important. Radioactive materials transported into the atmosphere by a large rising air current that accompanied the depression that passed over on March 15 were then transported by a strong westerly and diffused over the entire northern hemisphere, although at a low concentration (Takemura et al., 2011a, b; Stohl et al., 2011; FigureA3-3). According to the results of model calculations they reached the west coast of the United States a week later and Europe 10 days later, and were detected all over the world (e.g. Masson et al., 2011; Wetherbee et al., 2012; U.S. EPA, 2011; Priyadarshi et al., 2011).

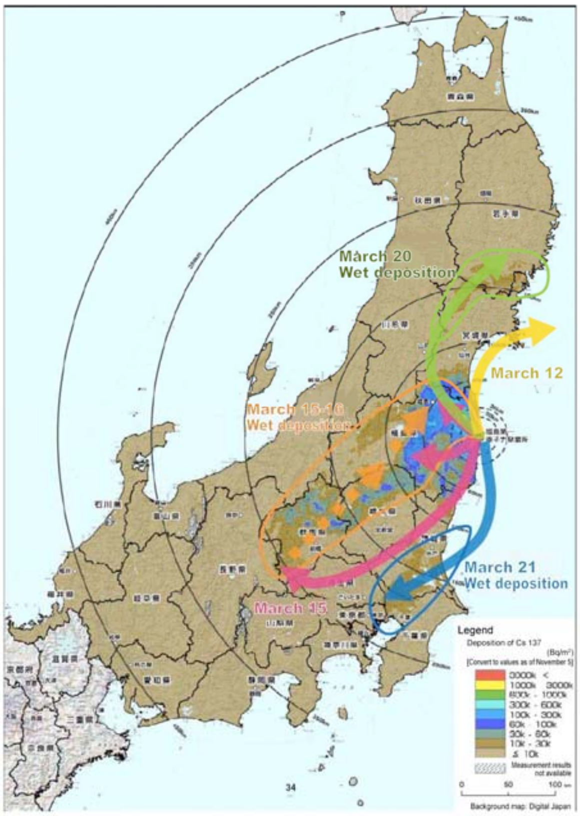

Figure A3-1. Route of radioactive plume via modeling and outline of deposition process The map shows the distribution of the deposition of cesium 137 via airborne monitoring (Prepared by partly modifying a JAEA public workshop document (2012))

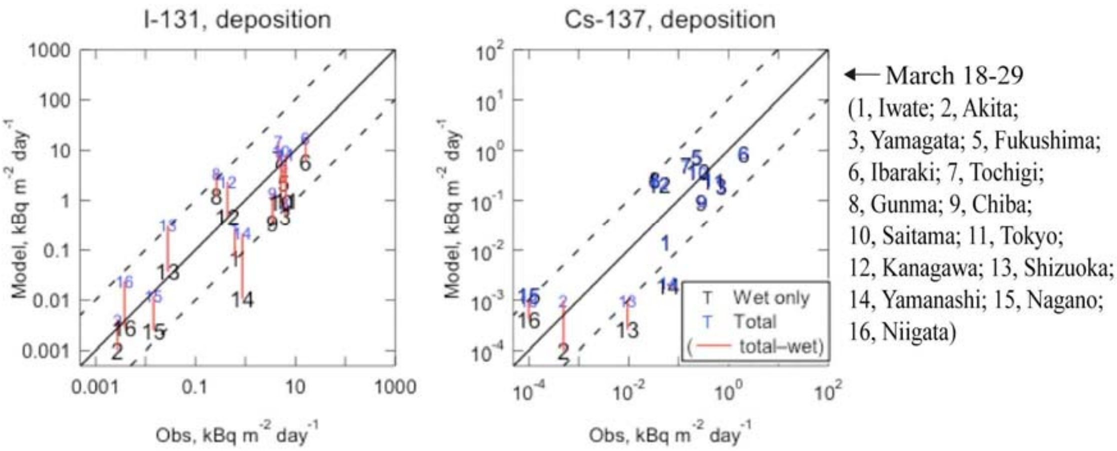

Figure A3-2. Comparison of modeling and observation results (monitoring of fallout by MEXT) on deposited amounts (Morino et al., 2011)

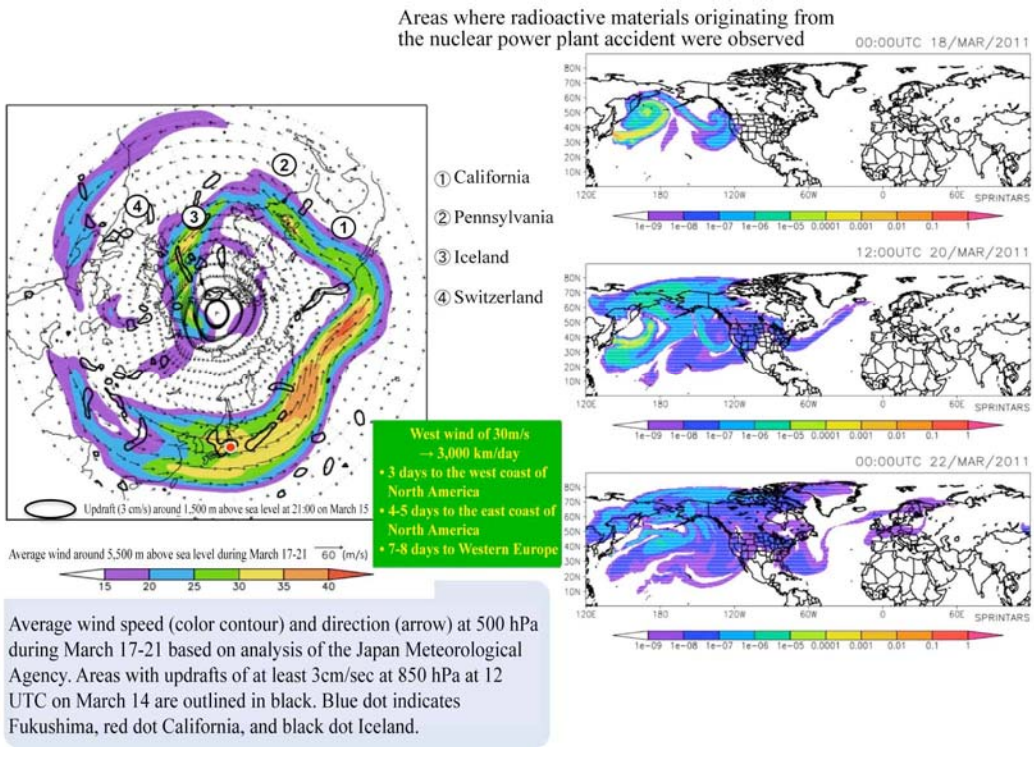

Figure A3-3. Modeling results suggesting possible global diffusion of emitted radioactive materials (Takemura et al., 2011a, b)

b. Current status with mapping of radioactive nuclear species fallout

Using the recommendation of the "necessity of the investigation of radiation levels after the accident of the Fukushima Daiichi Nuclear Power Plant" that was issued by

SCJ on April 4, 2011 as a start the joint team of the Ministry of Education, Culture, Sports, Science and Technology and universities collected 5 centimeters of soil from the surface layer at around five spots in approximately 2,200 locations within an approximately 100-kilometer radius of the Fukushima Daiichi Nuclear Power Plant, and then analyzed the nuclear species in the soil (FY 2011 Strategic Funds for the Promotion of Science and Technology "Study on Distribution of Radioactive Substances", published on march 13, 2012). Approximately 11,000 soil samples were collected, and the deposited amounts (radiation dose per unit area) of five types of gamma-ray emitting nuclear species, namely cesium 134, cesium 137, iodine 131, tellurium 129m, and silver 110m, then measured using a germanium (Ge) semiconductor detector and a map of concentration of the respective radioactive nuclear species in the soil created.

The results of the monitoring were then corrected in thereby improving the precision of the measured results of the airborne monitoring conducted during the same period of time. Comparison of the measurement results of airborne monitoring with the deposited amounts in soil at approximately 2,200 locations revealed them to be consistent, and thus subsequently conducted airborne monitoring over the whole of East Japan can also be regarded to have reproduced rather accurate deposited amounts. The measurement results of airborne monitoring can therefore be regarded as being useful as basic data for use in more comprehensive understanding of exposure routes to residents, the understanding of the actual situation with and dynamics of radioactive materials, and estimating the emitted amounts into the air, etc.

c. Process of transfer, diffusion, and concentration of the amount of radioactive nuclear species fallout over land

Radioactive material fallout over the land surface can be identified to have been transferred through the natural environment, including forests, soil, and rivers, etc., and thus requiring predictions of the changes in accumulated amounts of radioactive materials. Environmental monitoring of land has been conducted by the Ministry of Education, Culture, Sports, Science and Technology and the Ministry of the Environment to date. This section describes, being mainly based on results of the aforementioned monitoring, the process of the transfer/concentration of radioactive materials that can lead to better understanding of the exposure routes to residents at present.

The Ministry of Education, Culture, Sports, Science and Technology (2012) published a report on the analysis of the dynamics of radioactive materials in the Yamakiya region, Kawamata town, Date county, which is located in the upper reaches of the Kuchibuto River of the Abukuma River system.

The results of the study can be summarized as follows. (1) Transfer of radioactive cesium to soil water, stream water, and underground water was observed to have been small in scale at present. (2) In coniferous forests a large amount of radioactive cesium was present in the canopies, and the radioactive cesium was then gradually transferred to the forest bed in the process of passage through the canopies of rain that fell in the forests. (3) With regard to the amount of fine soil and sand particles discharged into rivers, a discharge of soil and sand of no more than 0.03% of the amount of fallen cesium into rivers was verified to have taken place in a 45-day long survey, even over bare land with little vegetation, but the amount of discharge of radioactive cesium was rather small over pastures and forests. With paddy fields it was mostly discharge into rivers when the fields were being prepared. (4) Over 90% of radioactive cesium flowed down into rivers in the form of floating sand, with the maximum total concentration of cesium 134 and cesium 137 of 126,000 Bq/kg being observed in the main stream of Abukuma River. This far exceeded 10 times the standard value for sludge. In addition, soil and sand with the same level of high concentrations accumulated in the reservoir of the main stream of the Abukuma River.

In addition, and according to a survey of the radioactivity concentration of radioactive materials before and after the rainy season in rivers (river water, river-bed soil, and floating sand) within Fukushima Prefecture that was conducted by the Ministry of Education, Culture, Sports, Science and Technology (2012), the radioactivity concentration of radioactive cesium in rivers tended to be high when the radioactivity concentration of radioactive cesium in the soil of the upper reaches was high (Figure A3-4). In addition, a positive correlation, although rather weak, was identified between the average radioactivity concentration of radioactive cesium in soil collected from the upper reaches and the radioactivity concentration of radioactive cesium in floating sand.

In contrast to this fine particles tended to absorb radioactive nuclear species in river-bed soil and an empirical formula of 0.65 times the specific surface area was therefore established for the concentration of radioactive cesium (He & Walling, 1997: Figure A3-5). Consideration thus needs be given to the fact that the measured values can significantly vary depending on the particle size composition in the river when making river-bed soil from a specific location an index for the contamination level. According to the Ministry of Education, Culture, Sports, Science and Technology

(2012) a positive correlation was also identified between the average radioactivity concentration of radioactive cesium in soil collected from the upper reaches and the radioactivity concentration of radioactive cesium in river-bed soil after making particle size adjustments, and thus the conclusion was drawn that the radioactivity concentration of radioactive cesium in the river water, river-bed soil, and floating sand at specified spots was likely to be capable of being estimated if the average radioactivity concentration of radioactive cesium deposited in the upper reaches of the water sampling locations were to be obtained.

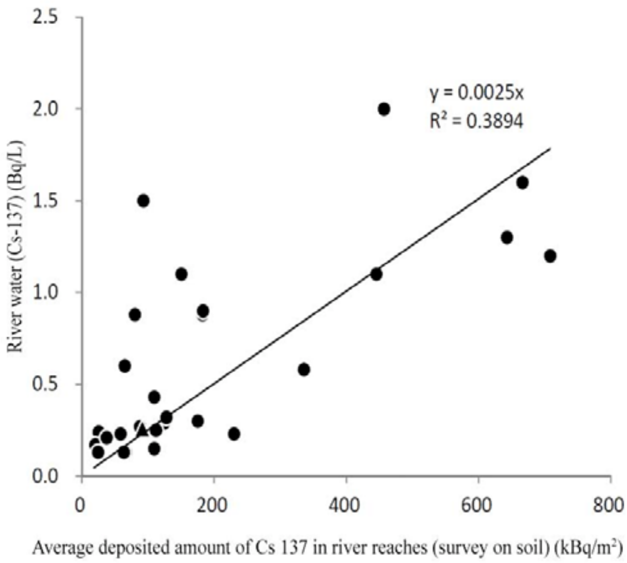

Figure A3-4. Relationship between average deposited amount in river reaches and concentration of cesium 137 in river water

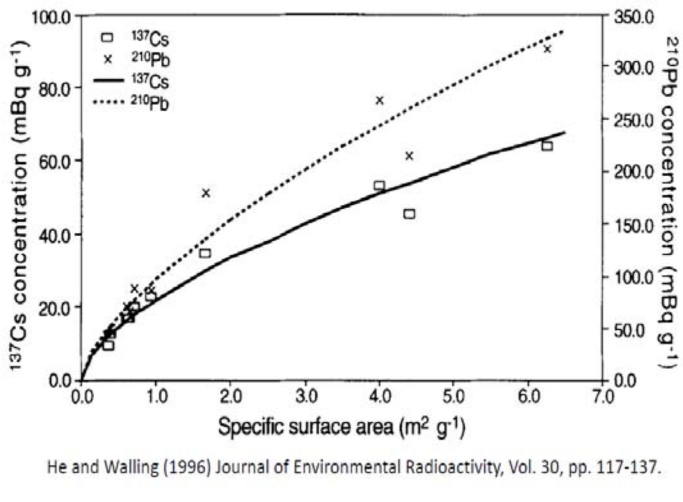

Figure A3-5. Relationship between specific surface area and concentration of cesium 137 in river water

d. Estimation of the relative contribution ratio of the amount of radioactive nuclear species fallout over land

Predicting the transfer/accumulation of radioactive species through utilizing a map of deposited amounts of radioactive materials would be enabled by better understanding of the deposited amounts over land surfaces and the outline of the dynamics of radioactive nuclear species described above, That is to say, if the deposited amount of radioactive cesium in river water, water-bed soil, and floating sand in the upper reaches and the average concentration at arbitrary water sampling locations were to be identified the radioactivity concentration of radioactive cesium in river-bed soil could then be estimated at different locations with various particle size characteristics after making particle size adjustments.

e. Process of advection diffusion of radioactive nuclear species into the ocean

Radioactive nuclear species emitted to the air, and around 2/3 of radioactive cesium in particular, were estimated to have been transported into the ocean and deposited over the surface of the ocean, thus becoming the source of radioactive materials within the ocean (Tsumune et al., 2012). Although many uncertainty factors exist with the estimated total amount, the results of many numerical simulations (Morino et al., 2011; Ohara, 2011; Tanaka, 2011; Takigawa, 2011) showed a remarkable distribution of the deposition over land in the northwest direction of the Fukushima Daiichi Nuclear Power Plant.

Radioactive cesium has been broadly detected in the surface of seawater in measurements made by voluntary observation ships and oceanographic research vessels, etc. that cross the North Pacific Ocean, etc. since the beginning of April. The figure of 196 Bq/m^{-3} for cesium 137, which was higher by two digits than that in surrounding waters, was locally measured (Aoyama et al., 2011). This was considered to be due to removal from the air via rainfall. In addition, radioactive nuclear species of Fukushima origin were detected in suspended solids and zooplankton sampled at a location of 47 degrees north latitude and 167 degrees east longitude, and 2,300 kilometers from the Fukushima Daiichi Nuclear Power Plant (Honda et al., 2011). Radioactive materials emitted into the air at the early stage after the accident and deposited over the surface of the ocean were thus surmised to have been absorbed.

With regard to monitored observations along the coastal areas and offshore, sampling of atmospheric aerosol and sea water was commenced upon on March 23 along a survey line 30 kilometers offshore from the Fukushima Daiichi Nuclear Power Plant using ships supplied by the Japan Agency for Marine-Earth Science and Technology and under the direction of the Ministry of Education, Culture, Sports, Science and Technology. And then from the middle of April on a number of voluntary research cruises were conducted by researchers of radioactive materials using both domestic and foreign ships. 15 Bq/m^{-3} of radioactive cesium was observed in atmospheric aerosol 30 kilometers offshore from the fixed point after April, thus indicating possible continued emissions into the air.

Both seawater and fresh water were used to cool the nuclear reactors and to supply water to the spent-fuel storage pool, with a large amount of high concentration radioactive nuclear species contaminated water then being produced. This then was considered to have been partly discharged directly into the ocean in front of the nuclear power plant. Tokyo Electric Power Co., Inc. (TEPCO) estimated that 0.9×10^{15} Bq of cesium 137 was discharged during April 1-6 from high concentration contaminated water being poured directly into the ocean from a crack in the front concrete wall of Unit 2. According to data on monitored observations made near the Fukushima Daiichi Nuclear Power Plant by TEPCO since March 21, 50,000 Bq/L of iodine 131 and 7,200 Bq/L of cesium 137 were observed on March 25 near the south outlet and 74,000 Bq/L of iodine 131 and 12,000 Bq/L of cesium 137 on March 26, thus suggesting possible discharges into the ocean of some form prior to April 1.

Monitored observations along coastal areas and offshore were commenced upon on March 23 at a survey line 30 kilometers offshore from the Fukushima Daiichi Nuclear Power Plant using ships supplied by the Japan Agency for Marine-Earth Science and Technology and under the direction of the Ministry of Education, Culture, Sports, Science and Technology. And then from the middle of April on a number of voluntary research cruises were conducted by researchers of radioactive materials using both domestic and foreign ships. Tsumune et al. of the Central Research Institute of Electric Power Industry examined the activity ratio of cesium 134 and cesium 137 using the above monitored observation data, and concluded that radioactive cesium observed near the surface of the ocean on March 25 or earlier had fallen from the air whereas that from March 26 on was directly discharged (Tsumune et al., 2012). In addition, a direct leakage scenario was estimated by comparing oceanic simulation and monitored observation data, and the amount of direct leakage until the end of May thus estimated to be 3.5±0.7PBq of ^{137}Cs, which was nearly four times the amount estimated by TEPCO. The estimation of the direct leakage scenario is essential in understanding the advection diffusion situation of radioactive materials. The estimation results of other leakage scenarios have also been reported (for example, by the Japan Agency for Marine-Earth Science and Technology, the Japan Atomic Energy Agency, and University of Toulouse in France, etc.). More reasonable estimations of leakage scenario will require comparisons being made using multiple models.

Radioactive materials directly discharged into the ocean get diffused through rather complex routes that are affected by ocean currents and the wind. Oceanic monitoring has been conducted from a relatively early stage, and which identified that 100 Bq/L or more of Cesium 137 had diffused to the north and south along the coast of Fukushima Prefecture by late March but which then gradually diffused to offshore in and after mid-April. However, the granularity in terms of time or space was rather rough, and therefore identifying a detailed advection diffusion situation using observed data is therefore rather difficult.

In parallel with oceanic monitoring simulations of the distribution of radioactive materials using multiple numerical models were conducted by the Japan Agency for Marine-Earth Science and Technology, the Central Research Institute of Electric Power Industry, and the Japan Atomic Energy Agency. The results of the abovementioned numerical models revealed high concentrations of radioactive materials to have diffused mainly in the south direction from the Fukushima Daiichi Nuclear Power Plant with a weak southward current in the coastal area of Fukushima Prefecture in late March, and that the major part of them would have been diffused further south or in a southeast direction due to the effects of the subsequent local wind and offshore current. By the middle of May part of them would have been transported into the northern edge of the Japan Current and then rapidly transported to the east. However, the results of the numerical models revealed a difference to be observable in the conditions of the offshore current of Ibaraki Prefecture with different models (Figure A3-6), and this also affected the assessment of the distribution routes of the radioactive materials. More detailed simulation research will therefore be needed in the future, including more precise numerical models and study on data assimilation methods, etc.

The results of numerical simulations consistently being conducted reveal that part of the radioactive materials will have reached the international date line around six months after the accident, but to have been diluted to a considerably lower level and with a concentration of approximately 0.01 Bq/L.

Effects on marine organisms were detected in sand eels that live in the surface layer of the ocean during April to May. Generally the concentration factor (simple ratio of radioactive nuclear species in sea water to that in organisms) of radioactive cesium in fish is 30 to 100 times, but the routes of transfer of radioactive materials from sea water to organisms vary and the biological concentration sometime takes place with the intake of bait or through the food chain, although depending on the nuclear species (Radioactive Waste Management Funding and Research Center, 1996). Accumulation of metal elements through their gills was observed with some types of fish. In addition, the concentration inside the body depends on the balance between intake and emission with cesium, etc., and thus the concentration inside the body is reduced by half within a time scale of a few days to several ten-days, although once again depending on the type of fish, when the concentration in sea water drops. According to the results of a survey on marine sediment, which has been fully implemented since around May, radioactive cesium contained in sediment in shallow water off the coast near Fukushima Daiichi Nuclear Power Plant has been gradually decreasing, but the rate of decrease is very slow when compared to radioactive cesium in sea water. From summer through to autumn high concentrations were also observed in offshore marine sediment in some cases. The possibility of that sediment affecting benthic organisms living there cannot be denied. In addition, the accident of concern can be characterized by the varying level of accumulation, and even with the same type of fish sampled from the same oceanic area. With flounders caught in the ocean around Fukushima Prefecture concentrations of over 4,500 Bq/Kg were observed in some, but almost none in others, and thus the concentration of nuclear species inside the body is considered to significantly vary depending on the biotope and route of transfer.

In addition to observations made of the radioactive nuclear species in seawater observations of the radioactivity concentration in marine soil have also been conducted since April 29, although mainly in coastal areas. A relatively high concentration has tended to be observable in clayey or silty fine particle sediment, with locally high radioactivity concentrations being observed in some cases. The observation points were limited in number, however, and hence details on the distribution in the air could not be obtained. However, examining the temporal changes in radioactive cesium at 12 fixed points along the coast reveals some locations offshore of Ibaraki Prefecture and offshore of Miyagi Prefecture away from the nuclear power plant to have had their concentrations in the surface of marine sediment increasing over time, thus suggesting the possibility of concentrations and transfer taking place evens after accumulation. In addition, no unified standards exist for the sampling of marine sediment, and the results of different sampling methods were intermixed, thus requiring care be taken with interpreting that data (Kanda, 2011).

Possible routes of the inflow of radioactive materials into the sea, other than the abovementioned direct discharge and falling from the air, include inflows from river and ground water systems. Of these observation data from rivers has been gradually becoming available, but not sufficient enough to include in the oceanic distribution simulation. No data is available for ground water systems.

(Distribution of cesium 137 as of May 1)

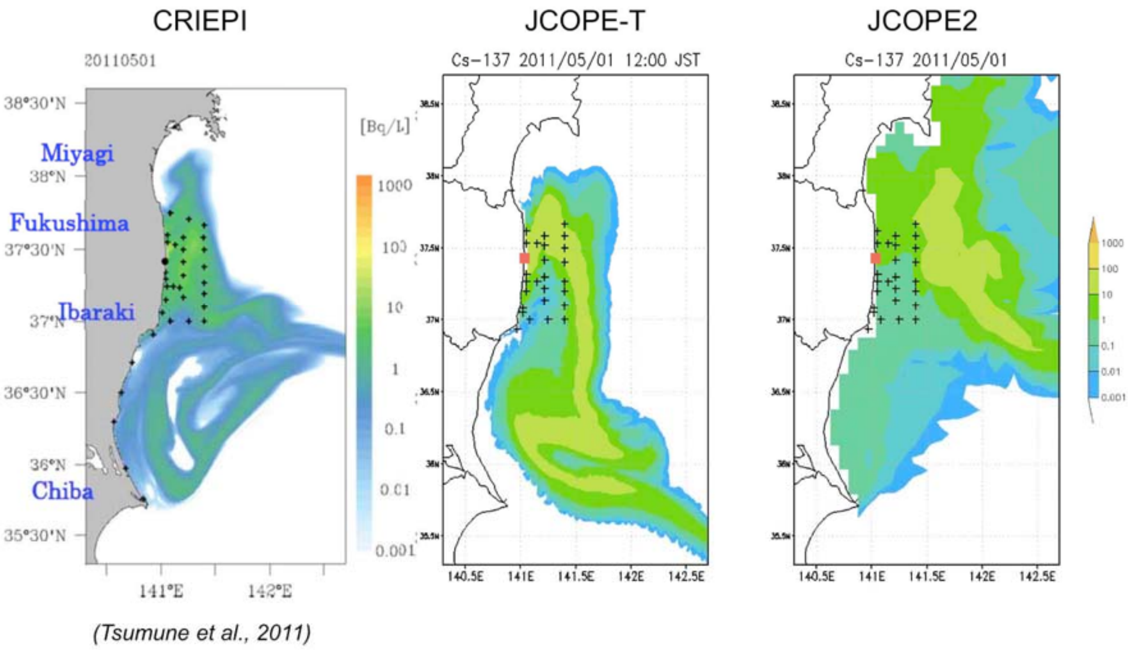

Figure A3-6. Simulation of distribution of cesium 137 concentration using oceanic model（Tsumune et al., 2012）

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