INSIGHTS CONCERNING THE FUKUSHIMA DAIICHI NUCLEAR ACCIDENT

Vol. 2&3

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Preface

The March 11, 2011 off the Pacific coast of Tohoku Earthquake (also known as the Great East Japan Earthquake) and the severe nuclear accident that was initiated mainly by huge tsunami following the earthquake, inflicted enormous damage to a wide-spread area of Japan. The precious lives of nearly twenty thousand people were lost and a great number of residences and commercial buildings were destroyed by the 9.0 magnitude (Mw) earthquake, one of the greatest quakes in history, and its devastating tsunami. After almost a decade, a large number of people still continue to suffer because of this natural disaster and accident, and live in temporary housing as evacuees. Whereas reconstruction is proceeding in general, some areas have not been restored yet. The huge tsunami after the earthquake damaged equipment of the emergency core cooling systems such as diesel generators of the three nuclear reactors of Units 1 through 3 at the Tokyo Electric Power Company (TEPCO) Fukushima Daiichi Nuclear Power Plant. The subsequent failure of the reflooding resulted in multiple large-scale core meltdowns of Units 1 through 3 under station blackout. During these events, many kinds of radionuclides in large quantities including ^{131}I (estimated at about 150 PBq) and ^{137}Cs (13 PBq) were released into the atmosphere. This multiple large-scale core meltdown accident is one of the worst nuclear accidents in the world up to now.

After the accident, the Editorial Committee of the Atomic Energy Society of Japan published a large number of commentaries on the various aspects related to the accident through the Society's monthly Japanese language bulletin, Journal of the Atomic Energy Society of Japan "*ATOMOΣ*". Moreover, scientific research papers have been published in the *Journal of Nuclear Science and Technology* in English, and also in the *Transactions of the Atomic Energy Society of Japan* in Japanese; both are scientific journals of the Atomic Energy Society of Japan. Within these Fukushima Daiichi nuclear accident-related articles, those written in Japanese were crucial to understanding the situation at that time inside Japan, but they are not easily accessed and understood by persons worldwide. To remedy this situation, we as the Editorial Committee of the Atomic Energy Society of Japan decided to translate them into English and open them to researchers and the general public everywhere. We believe how the accident was tackled and the lessons learned from it are worth considering for preparing countermeasures against severe accidents and for pursuing safer and more secure nuclear power plants.

The collected commentaries and research articles were published in the five-year period beginning just after the accident. Each document has a "chronicle-like importance". What we thought, what we were anxious about, what we expected, what we believed, and what we should do to tackle the accident during that time line were recorded. Professionals in various academic fields were asked to provide these commentaries that represented the most up-to-date information for the scientific community and the public. These records trace the recovery from this serious accident. Official reports on the nuclear accident at TEPCO's Fukushima Daiichi Nuclear Power Plant had been published by the Japanese Government, the IAEA, and the Atomic Energy Society of Japan; however it was not clear from these reports what we thought or what we were anxious about or what we wanted most to tackle at each time in Japan. Most of the commentaries were written not only for members of the Society but also for the public, including both those who were victims of the accident and those who were residents in Japan. The series of volumes that collected these articles has been entitled "Insights Concerning the Fukushima Daiichi Nuclear Accident, -Five Years' Comprehensive Archive Reports by Scientists and Engineers Published in Japanese from the Atomic Energy Society of Japan-". Each volume is entitled and includes selected articles as below.

Volume 1: **Fears and Concerns Just After the Accident, and Anxiety about Radiation**
Articles published in *ATOMOΣ* within one year after the accident, and articles on radiation effects on human published in *ATOMOΣ* from April 2012 to 2016

Volume 2: **Environmental Effects and Reconsideration of Nuclear Safety**
Articles on atmospheric dispersion, environmental remediation, decommissioning technology, nuclear safety and regulation published in *ATOMOΣ* from April 2012 to FY2016

Volume 3: I**mpacts on the Public**
Articles on social science published in *ATOMOΣ* from April 2012 to 2016

Volume 4: **Endeavors by Scientists**
Research and technical papers published in 2011-2016 in the *Transactions of the Atomic Energy Society of Japan*

Five years after the accident, many related articles still continued to be published. However, we thought that the situation during these first five years was more serious and, therefore it was more important to remember the articles appearing during this time. Many research papers published in the *Journal of Nuclear Science and Technology* (JNST) were written in English, and we have excluded them from these volumes. We ask interested readers to refer to these articles on the JNST journal web page, particularly in the special issues on the Fukushima Daiichi Nuclear Accident or papers identified as "Fukushima Daiichi NPP Accident related".

As we approach the end of the first quarter of the 21st century, populations are increasing rapidly in developing countries and improved living standards in those areas are sharply increasing energy consumption. At the same time, fears of great global environmental problems due to the consumption of fossil fuels are taking root, and there are also fears of food and safe water shortages. Among those issues, it is well accepted that an increase in atmospheric CO_2 concentration is causing global warming and abnormal weather patterns that may cause serious damage to life as we know it on the Earth. To reduce emissions of greenhouse gases while securing the energy necessary for our life is a great challenge for all of us. Moreover, at present coronavirus COVID-19 is spreading worldwide rapidly, and more than 82 million people were suffered and 1.8 million people have passed away as of the end of 2020, and numbers still rapidly increasing. A higher quality of life supported by sufficient energy also can reduce susceptibility to unknown diseases. In these regards, there were great expectations for nuclear energy as well as renewable energies. The most dangerous aspect of nuclear energy was revealed to the public by the Fukushima Daiichi nuclear accident. We must humbly recognize the risks involved in the enormous energy release from the atomic nucleus, and then, reconstruct a safer nuclear system than ever before, in light of the important lessons learned from the 2011 accident. We believe the collected expertise in the volumes of this series forms an indispensable history for that purpose.

Finally, we would like to express our deep gratitude to Mrs. Kumiko Kishimoto of the Atomic Energy Society of Japan for her helpful assistance in all stages of this publication.

Toshihiko Ohnuki
Toyohiko Yano
Naoki Yamano

Note: The contents of Volumes 1 to 3 are only selected articles from the *Journal Atomic Energy Society of Japan*, *ATOMOΣ*. Original Japanese articles can be accessed free of charge through J-STAGE website with color figures. Besides articles included into these volumes, so many commentaries/opinions/technical reports related to the Fukushima Daiichi Nuclear Plant Accident were published in *ATOMOΣ* from aftermath of the accident to date.

https://www.jstage.jst.go.jp/browse/jaesjb/63/2/_contents/-char/en

About the original Japanese papers in Volume 4, you can also access free of charge through web page of the *Transactions of the Atomic Energy Society of Japan* in J-STAGE.

https://www.jstage.jst.go.jp/browse/taesj/-char/en

Fukushima Daiichi Nuclear Plant Accident related papers already translated into English were excluded from this volume.

Administrative Map of East Part of Fukushima Prefecture

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Part II. Nuclear Safety and Regulation

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* Original date of Publishing in *ΑΤΟΜΟΣ* (in Japanese)

INSIGHTS CONCERNING THE FUKUSHIMA DAIICHI NUCLEAR ACCIDENT

Vol. 2

Environmental Effects and Reconsideration of Nuclear Safety

Articles on atmospheric dispersion, environmental remediation, decommissioning technology, nuclear safety and regulation published in *ΑΤΟΜΟΣ* from April 2012 to FY2016

Part I

Environmental Effect

Commentary

Environmental Remediation Cost in Fukushima Area
−Trial Calculation Using the Unit Cost Factor Method−

Cleanup Subcommittee, Atomic Energy Society of Japan,
Takeshi Ishikura and Reiko Fujita

Environmental remediation in Fukushima must be pursued in an appropriate and timely fashion using the right resource allocation and with a clear idea of the overall costs. A highly accurate cost estimate for the remediation of Fukushima cannot currently be made because appropriate methods for the decontamination of the target areas as well as treatment and disposal of the resultant soil and waste have yet to be determined. The latest findings should be applied so that the accuracy of rough estimates for the overall costs can be gradually improved. Given this, the Cleanup Subcommittee of the Atomic Energy Society of Japan (AESJ) has developed its own basic scenarios for trial calculations performed based on the announced workflow for the environmental remediation and the relevant unit costs. More specifically, the soil removed in the decontamination process was delivered to either interim storage facilities or controlled disposal sites depending on the level of contamination. An additional scenario involving restricted reuse was also considered. The approximate costs for these basic scenarios amounted to between 6 and 9 trillion yen.

I. Scope and Method for Estimating the Environmental Remediation Costs

1. Goal

A trial calculation was carried out for the areas contaminated by the disaster that occurred at the Fukushima Daiichi Nuclear Power Plant to roughly estimate the overall costs that would be incurred in conducting the decontamination, treatment, and storage offsite (i.e., outside the premises of the power station), thereby establishing basic case studies for the cost estimate. The decontamination of the target areas is aimed at reducing the annual dose rate to 1 mSv. A rough estimate of the overall costs was made for all zones with an annual dose rate of 1 mSv or more, while taking into consideration any treatments and disposal necessary to reduce the dose rate. In each zone with an annual dose rate of between 1 and 5 mSv, the decontamination efforts are focused only on those areas that have a high level of contamination (spot contamination) rather than the entire zone.

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2. Scope of Estimate

The cost estimate covers soil, specified waste (e.g., sludge from the water supply and sewerage systems specified in the Act on Special Measures concerning the Handling of Pollution by Radioactive Materials), and other waste materials produced by the total decontamination of areas with an annual dose rate of 5 mSv or more, which are mostly distributed throughout Fukushima, as well as that produced by the spot decontamination of areas with a rate of between 1 and 5 mSv. The scope of calculation extends from the decontamination process through to storage in industrial waste disposal sites (controlled disposal sites) or interim storage facilities, excluding final disposal after interim storage.

3. Estimation Method

The estimated overall costs were classified into decontamination costs, treatment costs, and storage costs. Based on the unit cost factor method, the cost of each item was calculated as a product of the unit cost and the quantity before being totaled according to the classification system to obtain a total figure for each category. The estimated cost items are presented in **Figure 1**.

The unit cost factor method is commonly used for estimating costs. In the early 1980s, the United States adopted this method to produce simple estimates of the costs involved in decommissioning. Later, the Nuclear Energy Agency (NEA; part of the Organisation for

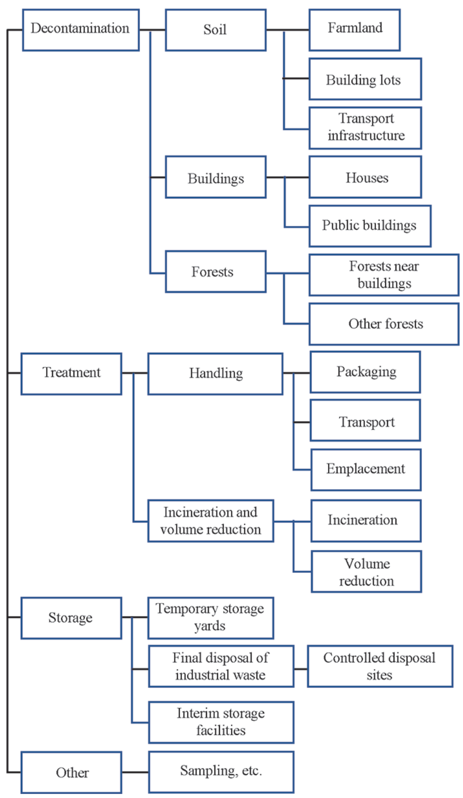

Figure 1 Estimated cost items

Economic Co-operation and Development (OECD)), the International Atomic Energy Agency (IAEA), and the European Union established and adopted an international standard for expense structures to enhance the accountability and transparency of decommissioning costs. In the mid-1980s, Japan adopted this method for estimating the costs involved in carrying out demolition work during the decommissioning process.

The accuracy of an estimate made using the unit cost factor method can generally be enhanced by applying more detailed and precise quantities and unit costs for more segmented cost items.

II. Scenarios for Waste Treatment

In this cost estimate, waste treatment is conducted in accordance with the Treatment Workflow for the Specified Waste and Other Waste Materials Produced by Decontamination [1] which was established by the Japanese Ministry of the Environment (MOE), (hereinafter referred to as the “MOE's workflow”). The following original policy was additionally instituted.

1. Waste Disposal Sites and Classification Thresholds

MOE sets forth key radiation thresholds for treating the specified waste and soil and any other waste materials produced during the decontamination process in the MOE's workflow. Thresholds of 100,000 and 8,000 Bq/kg are clearly specified for the storage of the specified waste. The workflow stipulates that any soil removed during the decontamination process shall be transported to either interim storage facilities or controlled disposal sites via temporary storage yards without any particular thresholds. The only exception is soil that can be incinerated. A safety assessment was conducted to verify the possibility of using storage for waste that clears the abovementioned threshold of 8,000 Bq/kg, which corresponds to an annual dose rate of 1 mSv or less for workers who work at a disposal site under normal waste treatment conditions throughout the operation period [2]. In this estimate, the soil and other waste materials produced in the decontamination process were assigned a threshold of 30,000 Bq/kg for radioactive cesium to decay over the course of 30 years to the level of 8,000 Bq/kg. Overall, the following thresholds were assigned (**Figure 2**).

- 100,000 Bq/kg: Lower limit for interim storage facilities
- 30,000 Bq/kg: Upper limit for controlled disposal sites

If soil and other waste materials within the range of between 8,000 and 100,000 Bq/kg are stored together at one disposal site in accordance to the MOE's thresholds, it would require rigorous monitoring for as long as 90 years or so [3] for waste to reduce the concentration of 100,000 Bq/kg to a level below 30,000 Bq/kg. As a solution, an original scenario was adopted for the decontamination and segregation of waste with a concentration of no more than 30,000 Bq/kg from that of 100,000 Bq/kg or greater. More specifically, any soil and waste materials produced during the decontamination process that have a concentration of no more than 30,000 Bq/kg are stored at controlled disposal sites for radioactive cesium to decay over the course of 30 years to a level below 8,000 Bq/kg, which is the storage period maintained by interim storage facilities. The key here is the use of a decontamination technology that can reliably treat the waste to reduce the concentration of 100,000 Bq/kg to a level below 30,000 Bq/kg. Volume reduction units (for the reduction of radioactivity through

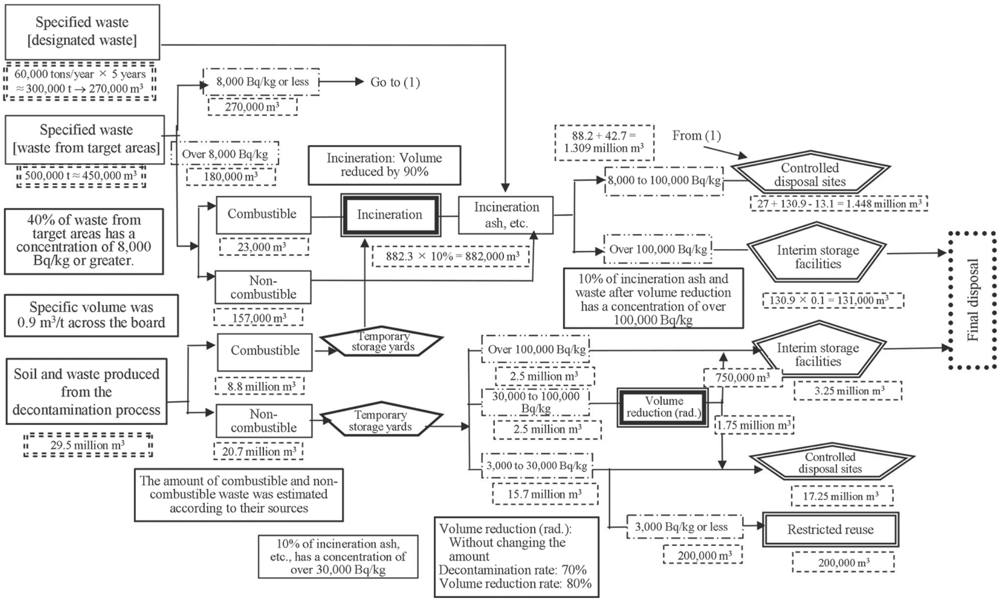

Figure 2 Workflow of waste amounts for treatment process

decontamination) are currently being developed and demonstrated with their practical application on the horizon. One example of this is the demonstration of a decontamination technology (hereinafter referred to as the “decontamination demonstration”) by the Japan Atomic Energy Agency (JAEA)[4, 5]. Realistically, not all of the waste with a radioactivity level of between 30,000 and 100,000 Bq/kg is eliminated. In this estimate, such waste would be accepted by interim storage facilities.

2. Scenario with Restricted Reuse

The MOE’s workflow does not provide explicit instructions concerning the reuse of waste. However, it does specify an average concentration of up to 3,000 Bq/kg as a guideline for the reuse of radioactive cesium under certain conditions[6]. Given that an enormous amount of waste is generated in areas outside the disaster site, its partial reuse is an effective solution even if the concentration exceeds the clearance level, provided proper shielding and containment are maintained for the targeted areas.

III. Amount of Treated Waste

In this estimate, the amount of waste was calculated according to the contaminated area corresponding to each dose rate classification stipulated in the MOE’s Estimated Amounts of Soil and Other Waste Materials Generated by Decontamination on a Case-by-Case Basis[7] (hereinafter referred to as the “basic waste data”). The decontamination rate, volume reduction rate, and other parameters related to the treatment process were adopted from, among other things, the actual performance during the decontamination demonstration conducted by the JAEA (e.g., efficiency in terms of incineration and volume reduction). Consequently, the workflow of the amount of the process was defined as shown in **Figure 3** based on the

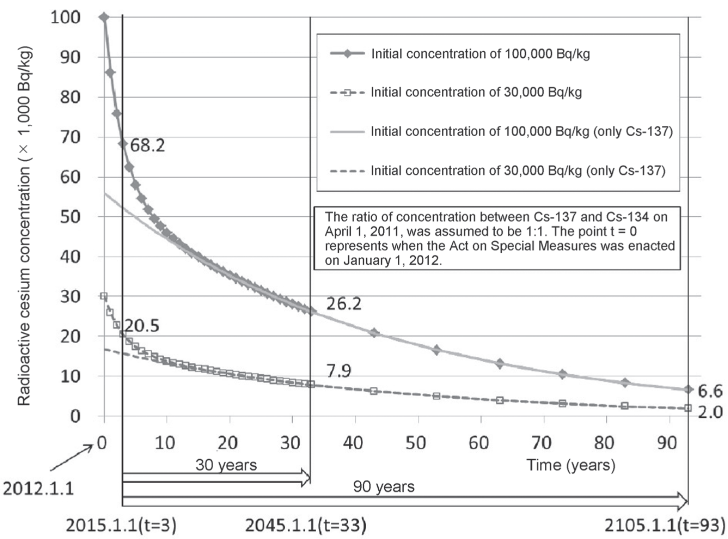

Figure 3 Reduction in radioactive cesium concentration over the years

following assumptions.

1. Amount of Decontamination Target

As mentioned above, the amount of treated waste was based on the basic waste data. Nonetheless, comparisons were made with other available data, such as that released by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) with regard to contaminated areas broken down by the dose rate category. These comparisons indicated that, in terms of the vast forests and farmland areas that require decontamination, the amount estimated based on the basic waste data was mostly higher, with only a slight difference in the calculated target areas. In contrast, the amount calculated based on other data tended to be higher in terms of land covered by buildings and building lots. Accordingly, the estimate based on basic waste data was considered appropriate due to the smaller share of costs involved in the decontamination of buildings and building lots and the higher costs incurred for farmland and forests.

2. Decontamination Methods

The decontamination targets were identified in accordance with the MOE's classification of land use [7]. The contamination methods were chosen accordingly for land (farmland, building lots, roads, and forests around housing), buildings, other forests, other infrastructure (schools, parks, etc.), and areas with spot contamination. Importantly, for farmland (paddies and fields), an effective method was applied to decrease the radioactivity in highly contaminated areas, whereas another method that produced much less waste was used for less contaminated areas.

The following decontamination methods were employed according to the intended targets (see **Table 1**).

(1) Farmland (paddies and fields): Topsoil removal, soil dressing, or other relatively robust

Table 1 Assessment of decontamination technologies and associated costs

No.	Target area	Annual dose rate (mSv/y)	Area or length (km², km)	Main material to be removed (/Volume 1,000 m³)		Applied technology	Unit cost	Addition rate for high dose rate	Addition rate assigned for other related expenses	Total (trillion yen)
1-1	Farmland (paddies and fields)	20 or more	88 km²	Soil	4,387*	Stirring of soil with water and removal (paddies); removal of topsoil and dressing of soil (fields)	950 million yen/km²	70%	50–90%	0.213–0.270
1-2		5–20	261 km²	Soil	13,038*	Topsoil removal and deep ploughing	400 million + 100 million = 500 million yen/km²	–	50–90%	0.196–0.248
1-3		1–5	899 km²	–	–	Deep ploughing, etc.	100 million yen/km²	–	90%	0.171
2-1	Buildings and building lots	20 or more	10 km²	Soil	193*	Buildings: Washing Building lots: Topsoil removal, soil dressing, and vegetation removal	650 million + 375 million + 250 million = 1.275 billion yen/km²	70%	50–90%	0.033–0.041
2-2		5–20	41 km²	Soil	831*			–	50–90%	0.078–0.099
3-1	Key transport infrastructure (262 km/km²)	20 or more	4 km²* ⇒ 1,050 km	Sludge	17*	Washing of road surfaces and cleaning of side ditches (both)	2.4 million yen/km	70%	50–90%	0.006–0.008
3-2		5–20	9 km²* ⇒ 2,360 km	Sludge	33*			–	50–90%	0.008–0.011
4-1	Forests around housing (1%)	20 or more	41* × 1/10 = 4 km²	Vegetation Soil	37 200	Removal of fallen leaves, pruning of trees, removal of topsoil, and dressing of soil	760 million + 580 million + 375 million = 1.715 billion yen/km²	70%	50–90%	0.017–0.022
4-2		5–20	93* × 1/10 = 9 km²	Vegetation Soil	84 450			–	50–90%	0.023–0.029
5-1	Forests (10%)	20 or more	41 km²*	Vegetation	367	Removal of fallen leaves and mulch layer (on slopes), pruning of trees, construction of road networks, clearance of removed materials, and construction to prevent topsoil runoff	760 million + 580 million + 500 million = 1.84 billion yen/km²	70%	50–90%	0.192–0.244
5-2		5–20	93 km²*	Vegetation	839			–	50–90%	0.257–0.325
6-1	Forests (remaining 90%)	20 or more	367 km²*	Vegetation	2,295	Pruning	580 million yen/km²	70%	50–90%	0.543–0.688
6-2		5–20	842 km²*	Vegetation	5,257	Pruning		–	50–90%	0.733–0.928
7-1	Other infrastructure (schools, parks, etc.)	20 or more	5 km²*	Soil	245	Topsoil removal, soil dressing, and vegetation removal	375 million + 250 million = 625 million yen/km²	70%	50–90%	0.008–0.010
7-2		5–20	18 km²*	Soil	883			–	50–90%	0.017–0.021
8	Spot contamination	1–5	642 km²	Sludge	399*	Cleaning of side ditches, removal of topsoil, etc.	375 million yen/km²	–	90%	0.457
	Subtotal	Annual dose rate	Area subtotal	Contaminated material and property/Subtotal		20 or more	5–20	5 or less		2.952–3.572
		20 or more	519 km²	Soil	Non-combustible/20,227	5,025	15,202	0		
		5–20	1,273 km²	Sludge	Non-combustible/449	17	33	399		
		1–5	1,541 km²	Vegetation	Combustible/8,879	2,699	6,180	0		
9	Temporary storage yards	–	–	29,500		–	32 million yen/1,000 m³	–	–	0.944
–	Total	–	–	–		–	–	–	–	3.896–4.516

Note: (1) Figures marked with an asterisk are assigned based on Cases 1-3, 2-3, and 3-1 in Table 5 (area) and Table 6 (amount of removed soil, etc.) in Reference 7). The figures in Sections 1-3, 4-1, and 4-2 in the table were determined according to the original policy.

(2) The addition rate assigned for other related expenses in the table was 50% for decontamination in concentrated areas and 90% for decontamination in dispersed areas. The addition rate of 90% was assigned across the board for a more conservative estimate with greater expenses. These addition rates were assigned with reference to the MOE's standards for the formulation of provisional cost estimates for decontamination and other work performed in special decontamination areas (May 2012).

methods were employed in areas with an annual dose rate of 20 mSv or more. In areas within the range of 5 to 20 mSv/year, methods such as topsoil removal and deep ploughing were employed. In dealing with spot contamination, deep ploughing was chosen to minimize the amount of waste that was produced.

(2) Building lots (including public facilities): Topsoil removal, soil dressing (or the construction of simplified temporary storage yards), and vegetation removal.

(3) Buildings (houses and public facilities): Washing (cleaning, wiping, scrubbing, etc.)

(4) Key transport infrastructure (roads and side ditches): Washing of road surfaces and cleaning of side ditches (both).

(5) Woods around housing: Vegetation removal (pruning and the removal of fallen leaves), topsoil removal, and soil dressing were employed within about 20 m of the housing. These methods were applied to about 1% of the total target forest area.

(6) Forests: Forests fulfill a variety of functions, such as recharging groundwater, preventing landslide disasters, and helping to conserve soil, biodiversity, and the global environment. Extending from areas located near settlements into the remote mountains, they are used in many different ways [8)]. These functions may be impaired if a thorough decontamination is performed with the sole aim of reducing exposure. Each forest should be classified according to how contaminated its trees are and the way people use it (i.e., how frequent they access or approach it). Once forests have been divided into the following categories, the decontamination methods should be chosen after a comprehensive assessment of the migration of contaminants to the forest floor and their impact on water sources: forests near houses and the like; forests regularly accessed for use by people; and other forests. As of the time of writing, no reliable assessment findings were available. Hence, this estimate assumed that 10% of the total forest area (134 km^2) would require prioritized decontamination, which consists of the removal of vegetation (pruning and the removal of fallen leaves), the construction of road networks for carrying out decontamination, the clearance of removed materials, and the protection of road surfaces with gravel and other such measures for preventing sediment runoff. The cost estimate for the remaining forests (90%) was performed by taking into consideration all of the expenses in a batch and assuming that the decontamination would be performed simply by pruning and the like. The determination of specific decontamination methods was left for future development. Decontamination may need to be repeated because forest contamination tends to migrate from elevated terrain to low terrain.

(7) Other infrastructure (schools, parks, etc.): As was the case for building lots, the methods chosen were topsoil removal, soil dressing (or the construction of temporary storage yards), and vegetation removal.

(8) Spot decontamination: Mainly the removal of sludge from locations where radioactive materials tend to accumulate (e.g., water collection points leading from gutters and moss clumps), the cleaning of side ditches, and the removal of topsoil were chosen.

3. Temporary Storage Yards

The MOE's workflow stipulates that the soil and waste produced by the decontamination process shall be collected at a temporary storage yard before transportation to interim storage facilities (in Fukushima Prefecture) or controlled disposal sites (outside Fukushima Prefecture). Accordingly, this estimate also assumed that temporary storage yards would be established.

4. Waste Treatment Methods

As stipulated in the MOE's workflow, this estimate assumed that waste would be treated by incineration or volume reduction.

(1) Incineration

Incineration can be divided into high-temperature incineration and low-temperature incineration. With reference to the decontamination demonstration conducted by the JAEA, the most common value of 10% was assigned as the volume reduction rate. Radioactivity was concentrated into incineration ash.

(2) Volume reduction

Many types of methods and systems can be used to reduce the volume of waste. In this estimate, taking the JAEA's decontamination demonstration into consideration, the two methods indicated below were postulated for use in the case of radioactive materials exceeding a certain level of concentration. The total amount of waste was assumed to remain the same before and after the volume reduction.

- Sorting and washing of soil by grain size
- Thermal and chemical treatment applicable to common materials

The performance and costs vary according to the method used. Nonetheless, moderate performance has been achieved with the relatively inexpensive sorting and washing of soil by grain size (decontamination rate: 70%; volume reduction rate: 80%). At the same time, high performance has been achieved with the relatively expensive thermal and chemical treatment (decontamination rate: 90%; volume reduction rate: 95%)[5]. In terms of their decontamination and volume reduction performance, these two methods proved to incur almost the same total costs for volume reduction and subsequent storage. The difference in total costs between these two methods was marginal, although they did vary depending on certain conditions. In this estimate, therefore, the figures from sorting by grain size were assigned because that method has been tested in other areas. The cost estimate was given a wide range in anticipation of the development of high-performance volume reduction technologies (e.g., chemical treatment) for waste that has complex properties and is hard to decontaminate.

5. Storage

(1) Properties of waste and storage

Specified waste can be divided into combustible waste and non-combustible waste. In principle, combustible waste is incinerated into ash, while non-combustible soil and the like are stored in a disposal site without being incinerated. The incineration ash and soil that are generated by the decontamination process can also be categorized in terms of the leachability associated with the difference in their properties in adsorbing cesium. In particular, cesium tends to leach out of the fly ash produced by incineration.

(2) Thresholds for storage and reuse

The acceptance criteria for the respective destination originally assigned for this estimate are presented as follows.

(i) Acceptance threshold for interim storage facilities: Over 100,000 Bq/kg

The lower limit was set by assigning the value specified in the MOE's workflow for the waste (e.g., soil and incineration ash) produced by the decontamination conducted in Fukushima Prefecture. Currently, the feasibility has yet to be verified with regard to the proper treatment and disposal of waste by reducing its concentration of between 30,000 and 100,000 Bq/kg to below 30,000 Bq/kg. For this reason, after volume reduction was conducted for the target waste, the rate of acceptance at controlled disposal sites was lowered (the decontamination rate requirement was lowered from 80% down to 70%) and the rate of acceptance at interim storage facilities was increased.

(ii) Acceptance threshold for soil and other waste at controlled disposal sites: 30,000 Bq/kg or less

The upper limit is set to 30,000 Bq/kg. A guide level of 8,000 Bq/kg is provided for the lower limit to ensure that the annual exposure of workers to waste is limited to no more than 1 mSv under normal conditions. However, the specified waste and other waste materials as well as the soil produced during the decontamination process shall be accepted even if their concentration levels are below 8,000 Bq/kg (according to the MOE's workflow).

(iii) Restricted reuse: 3,000 Bq/kg or less

A threshold of 3,000 Bq/kg was assigned on the basis that it is below 8,000 Bq/kg but a few dozen times higher than the clearance level [7].

IV. Setting Unit Costs

1. Unit Costs for Decontamination

The unit costs for decontamination were set in accordance with the MOE's guidelines for decontamination projects [9]. Reference was also made to actual records from the JAEA's decontamination demonstration to assign unit costs for pruning, the removal of fallen leaves, and so on. A similar unit cost as that used for controlled disposal sites was assigned for the acceptance of waste at temporary storage yards. In addition, a factor of 1.7 was assigned to areas with an annual dose rate of 20 mSv or more as decontamination takes more time than normal work due to the need to prepare protection against radiation.

2. Unit Costs for Treatment

The unit costs were adopted from published sources (see **Table 2**).

(1) Incineration and volume reduction

The unit costs for incineration and volume reduction were assigned with reference to projects such as the decontamination demonstration conducted by the JAEA.

(2) Packaging, transport, and emplacement

The treatment workflow was divided into two types: the first type is incineration followed by transport before temporary storage while the other is incineration followed by transport after temporary storage. The unit costs were assigned with reference to the calculation of civil engineering costs by local governments.

(3) Sorting according to the measured concentration and monitoring

Waste must be sorted according to the measured radioactivity concentration in each treatment process. In this estimate, the sorting costs were included in the cost of storage.

Similarly, the costs involved in monitoring the waste disposal sites once they have started operating were also included in the cost of storage.

Table 2 All expense items for decontamination, treatment, and storage—Case 1 (see Note (3) regarding Case 2)

No.	Category	Item	Amount [× 10,000 m³]	Unit cost [× 10,000 yen/m³]	Addition rate for other related expenses	Total [trillion yen]
1	Decontamination	Decontamination subtotal (including temporary storage yards)	See Table 1			3.896–4.516
2	Treatment	Incineration	882.3	5	50%	0.662
		Volume reduction, etc. (sorting, etc.)	250	2	50%	0.075
		Alternatives for volume reduction, etc. (chemical treatment, etc.)	As above	7.5	As above	(0.281)
		Incineration followed by transport before temporary storage (up to a distance of 10 km)	2,995	0.24	--	0.072
		Incineration followed by transport after temporary storage (distance of 100 km)	2,201	0.31	--	0.068
		Treatment subtotal				0.877–1.083
3	Storage	Temporary storage yards	Included in decontamination			--
		Controlled disposal sites/removed soil, etc.	1,725	3.2	--	0.552
		Controlled disposal sites/incineration ash	144.8	As above	--	0.046
		Interim storage facilities/removed soil, etc.	325	10.0–18.0	--	0.325–0.585
		Interim storage facilities/incineration ash	13.1	As above	--	0.013–0.024
		Restricted reuse	20	3.2	--	0.006
		Storage subtotal				0.942–1.213
4	Other	Monitoring, etc.	Included in storage			--
	Total		--	--	--	5.715–6.812

Note: (1) The cost associated with the "Monitoring, etc." item in the table was included as a cost for storage.
(2) The "Addition rate for other related expenses" item in the table was set to 50% based on the fact that most expenses are concentrated in decontamination target areas (treatment facilities) (see Note (2) in Table 1).
(3) Case 2: A unit cost of 500,000–800,000 yen/m³ was assigned to interim storage facilities. Subtotal for storage: 2.295–3.309 trillion yen. Total: 7.068–8.908 trillion yen.

3. Unit Costs for Storage

The unit costs involved in storage were adopted from published sources, as presented in Table 2.

(1) Setting unit costs for storage

Since no specific approaches have been established for the storage of waste with two different types of properties (i.e., leachable and non-leachable), and also bearing in mind their radioactive nature, the same higher unit cost was assigned for both types of waste.

[i] Temporary storage yards: The same unit cost for accepting waste as that in controlled disposal sites.

[ii] Controlled disposal sites: The highest market price was applied to the unit cost for accepting waste [10].

[iii] Interim storage facilities: Two cases were examined, with one using the market price for shielded disposal sites (disposal sites for hazardous materials and other industrial waste) and the other using the unit price for the storage of radioactive waste. See Section (2) below for details.

[iv] Restricted reuse: Restricted reuse involves costs associated with producing recycled products. In practice, these costs vary significantly according to the intended purpose. However, a high unit cost runs contrary to the purpose of reuse. Consequently, this estimate applied the same unit cost because waste is accepted at controlled disposal sites, which can be regarded as a target level for producing recycled products.

[v] Final disposal after storage at interim storage facilities: Not considered in this estimate.

(2) Alternative unit costs proposed for the acceptance of waste at interim storage facilities

The following cases were considered in the setting of unit costs involving the use of interim storage facilities.

– Case 1: A level comparable to that of shielded disposal sites

– Case 2: A level comparable to that for the storage of radioactive waste (a sort of shallow trench disposal site)

Note: Shallow trench storage is an institutional practice involving the shallow burial of chemically stable waste (e.g., concrete and metals) from nuclear power stations with extremely low levels of radioactivity.

V. Estimate Results

The estimate costs were within the range of 5.7 to 6.8 trillion yen in Case 1 and 7.1 to 8.9 trillion yen in Case 2 (Tables 1 and 2). This calculation did not include the costs involved in conducting the final disposal after storage at interim storage facilities.

No.	Item	Case 1	Case 2
1	Decontamination (including temporary storage yards)	3.90–4.51	3.90–4.51
2	Treatment (packaging, transport, emplacement, incineration, and volume reduction)	0.88–1.08	0.88–1.08
3	Storage (controlled, interim storage, and reuse)	0.94–1.21	2.30–3.31
	Total	5.72–6.81	7.07–8.91

VI. Future Tasks

This estimate of the total environmental remediation costs was conducted using basic scenarios and an additional original scenario. It was produced based on the workflow, amount, and unit costs specified by the MOE. Going forward, greater precision should be pursued in accordance with the types and properties of the respective waste targets.

Concerning the waste amounts, this estimate utilized basic waste data from the MOE after ensuring that there were no significant discrepancies with other major databases. Further precision with respect to the amounts involved should be pursued in line with the actual state of contamination.

The performance of each decontamination method has been demonstrated in the field tests conducted in FY2011 by the JAEA and so forth. Nonetheless, their technical reliability must be enhanced to ensure effective and efficient work at the site.

In this estimate, most unit costs were based on the MOE guidelines for decontamination projects. The remaining unit costs were compensated for based on experience gained from the decontamination demonstration conducted by the JAEA. Going forward, a wider range of empirical unit costs should be adopted. In particular, unit costs associated with storage may be reduced by assigning the appropriate disposal sites for waste according to the levels of leachability and other such properties.

The authors owe a debt of profound gratitude to the members of both the Cleanup Subcommittee (headed by Tadashi Inoue) and the Cost Evaluation Working Group of the Atomic Energy Society of Japan for their deliberations and reviews of this paper.

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Report

Results of Removing Radioactive Cesium from the Shallow Rice Fields by Planting Sunflower

−Report from the Survey Team on the Absorption and Adsorption of Cesium by Planting Sunflower−

Japan Atomic Energy Agency, **Osamu Amano**

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

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

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

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

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

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

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

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

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

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

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

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

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

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

V. Investigation on Decontamination Using Sunflower Plants

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

VI. Measurement Method Employed on Site

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

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

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

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

VII. Results from Measurements Taken of Soil and Sunflower Plants

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

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

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

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

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

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

VIII. Validation of Results

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

IX. Discussion on the Mechanism

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

X. Tasks Ahead: Way Forward to Unravel the Mechanism

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

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

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

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

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

XI. Conclusion: Effectiveness of Decontamination Using Sunflowers

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

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Verification! Predicted Information Provided from SPEEDI during the Fukushima Daiichi Nuclear Accident

−Accuracy, Timeliness, and Future Utilization−

Japan Atomic Energy Agency, **Masamichi Chino**

In swift response to the accident that occurred at TEPCO's Fukushima Daiichi Nuclear Power Plant, SPEEDI has been providing information to relevant agencies in accordance with the established manual. A failure to take this information into account when decisions were taken regarding evacuations and other measures caused considerable controversy. This commentary examines the types and timing of the predicted information that SPEEDI provided during the accident. It then verifies the accuracy of the predictions through a comparison with the monitoring data obtained from actual measurements before considering future utilization of SPEEDI.

I. Introduction

SPEEDI facilitates preparations for a massive release of radioactive materials from nuclear power plants or elsewhere by quickly predicting the atmospheric concentration of the radioactive materials and the exposure dose in the surrounding environment through computer simulations.

The Investigation Committee on the Accident at the Fukushima Nuclear Power Plants of Tokyo Electric Power Company (ICANPS), the Independent Investigation Commission on the Fukushima Daiichi Nuclear Accident, and the report published by the Japanese government for the IAEA Ministerial Conference on Nuclear Safety all concluded that SPEEDI should have been proactively employed for the evacuation measures implemented in response to the nuclear accident at the Fukushima Daiichi Nuclear Power Plant. However, the National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission (NAIIC) concluded that the computational predictions produced by SPEEDI had limited usefulness in relation to making decisions on evacuation measures and that it is necessary to reinforce emergency monitoring measures instead.

To deepen this discussion, it is essential that we examine some basic points. First, what types of predicted information did SPEEDI provide in relation to this accident and when was such information provided to the relevant agencies? Second, how accurate was this information in comparison to the monitoring data that was subsequently obtained? On September 21,

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2012, the prefectural government of Fukushima published on its website data obtained from environmental monitoring posts within a range of 30 km from the Fukushima Daiichi Nuclear Power Plant, where sheltering and evacuation measures were conducted [1)]. To some extent, this data made it possible to keep track of temporal and spatial changes in the air dose rate within this range.

This commentary examines the results of the predictions provided by SPEEDI and the timing of their provision to the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the now defunct Nuclear and Industrial Safety Agency (NISA). These predictions were later uploaded to their respective websites. The commentary then discusses the timeliness and accuracy of the information provided to the relevant agencies by SPEEDI. Based on the author's findings, possible future utilization for SPEEDI is explored.

II. Types, Accuracy, and Timeliness of the Data Provided by SPEEDI

The predicted information provided by SPEEDI can be roughly divided into the results of either regular predictions or on-demand predictions.

Regular predictions are made by assuming that the release of a unit amount (1 Bq/h) of radioactive materials begins every hour on the hour to present the hourly movements of radioactive plumes in the form of the air dose rate distribution and the like. During the Fukushima Accident, regular predictions were commenced at 4 p.m. on March 11, 2011, to provide information to the relevant agencies every hour on the hour. Initially, the distribution was predicted up to 2 hours later within a range of $25 \times 25\ km^2$. As the contaminated areas grew, this range was expanded to $100 \times 100\ km^2$, starting from 8 a.m. on March 16. At that point, predictions were made up to 3 hours later.

On-demand predictions are conducted under the conditions specified by NISA's Emergency Response Center (ERC) and Off-site Center (OFC), the now defunct Nuclear Safety Commission (NSC), and other such bodies to assess the environmental impact of escalating events, plan emergency environmental monitoring, inversely estimate the amount of radioactive materials released, and assess the dose based on the estimated amount of release.

This commentary first examines the ability of SPEEDI to predict the movements of the radioactive plumes based on the results obtained from regular predictions and identifies the weather conditions that caused a reduction in accuracy. Subsequently, the accuracy and timeliness of the information provided are examined based on on-demand predictions, such as the prediction of the impact of the venting and the hydrogen explosion requested by the ERC as well as the prediction of the dispersion requested by the OFC to plan emergency monitoring measures. The examination period mainly covers March 11 to 16 when information was frequently provided to the ERC, OFC, and other such bodies.

1. Characteristics during the Examination Period Described from the Observation Data

The examination begins with an overview of the movements of the radioactive plumes from March 11 to 16 using data obtained from various monitoring posts in Fukushima Prefecture. The distribution of these monitoring posts is represented by small circles in **Figure 1**. On this map, the location names are indicated by the posts mentioned in the

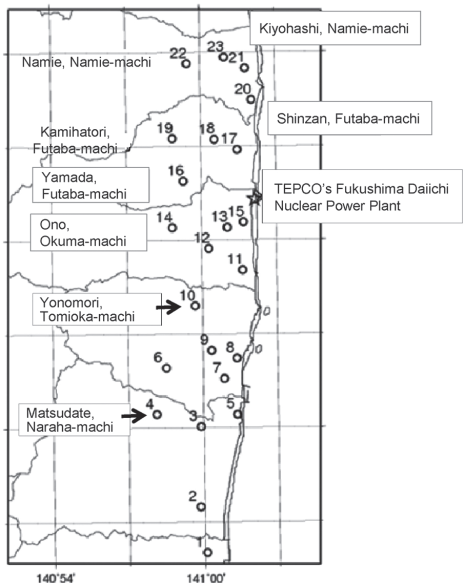

Figure 1 Locations of monitoring posts

commentary.

March 12: Beginning in the morning, increases in the air dose rate of up to 30 μSv/h were observed at several posts. These increases are probably associated with leaks from the primary containment vessel. The major atmospheric release is believed to have taken place in the afternoon from 14:30 to 15:00 when the drywell pressure dropped sharply as a result of the venting conducted at Unit 1. The increase in the air dose rate to 1,590 μSv/h that was observed at 3 p.m. in Kamihatori, Futaba-machi (5.6 km northwest (NW), and the subsequent reduction in the dose rate on the ground surface to 30 μSv/h by March 15 are probably associated with the plume produced by a wet venting with a large amount of noble gases and a relatively small amount of iodine and cesium. At 15:36, Unit 1 experienced a hydrogen explosion. At 5 p.m. in Shinzan, Futaba-machi (3.9 km NNW), the air dose rate increased to 904 μSv/h. In contrast to the case in Kamihatori, the dose rate on the ground surface had only declined to around 200 μSv/h by March 15 after the plume passed over that area. Considering the observed wind direction, the increase in the dose rate can be ascribed to the hydrogen explosion.

March 13–14: On March 13, the pressure of the drywell increased and venting was performed several times at Unit 3. Temporary increases in the air dose rate of up to a few dozen μSv/h were observed at several posts along the coast. However, the significant increases that had been observed in the previous afternoon did not occur because the plumes were carried seaward due to the weather conditions. On March 14, venting was performed at Unit 3, which subsequently experienced a hydrogen explosion. However, the weather conditions continued to carry the plumes seaward until the evening. At night, the dose rate began to increase in the area to the south of the site.

March 15–16: From about 7 to 8 a.m. on March 15, the dose rate began to increase to 41 μSv/h in Yonomori, Tomioka-machi (7.3 km SSW), and to 19 μSv/h in Matsudate, Naraha-machi (14.2 km SSW), both of which are located to the south of the Fukushima Daiichi Nuclear Power Plant. The posts that observed these increases shifted in a clockwise direction over time. At around 11 a.m., the post in Ono, Okuma-machi (4.9 km WSW), registered 390 μSv/h, which was followed by an increase to 232 μSv/h in Yamada, Futaba-machi (4.1 km WNW), at 1 p.m. and an increase to 32.1 μSv/h in Namie, Namie-machi (8.6 km NNW), at 9 p.m. By then, the flow of plumes had reversed from clockwise to counter-clockwise. As a result, the dose rate increased again in Yamada, Futaba-machi, to 1,020 μSv/h at 0 a.m. on March 16. Subsequently, the post in Ono, Okuma-machi, registered 173 μSv/h at 1 a.m. and the measurement in Matsudate, Naraha-machi, peaked at 44.5 μSv/h at 3 a.m. After that, the plumes probably flowed seaward in a south-southeast direction. After the dose rate increased between 11 and 12 a.m. on March 16 in Matsudate, Naraha-machi (33 μSv/h), and in Ono, Okuma-machi (324 μSv/h), the plumes are believed to have travelled seaward until the morning of March 20.

Due to space limitations, this commentary cannot present an examination of all of the plumes. Instead, it will examine the predictions made for the afternoon of March 12 and a period covering March 15 to 16, when major increases in the dose rates were observed onshore.

2. Accuracy of Regular Predictions [2)]

Figure 2 presents the results of regular predictions that assume a release at 2, 3, and 4 p.m. on March 12 with the venting taking place between 14:30 and 15:00 as well as the hydrogen explosion (15:36). The predictions chronologically present the air-absorbed dose rates 2 hours after the release. On March 12, the wind direction shifted clockwise from about noon. The increase in the dose rate in Kamihatori, Futaba-machi, at 3 p.m. caused by venting is reproduced by the predicted plume (figure in the center) from the release at 3 p.m. with a lag of 1 to 2 hours. The movement of the plume from the hydrogen explosion is predicted almost accurately by the predicted plumes from the release at 3 and 4 p.m. (figures in the center and on the right), which reached Shinzan, Futaba-machi, and Namie, Namie-machi when the dose rates increased at 5 p.m.

Figure 3 shows the results of regular predictions produced by SPEEDI that were released on March 15 and 16. They present the distribution 2 hours after the release every hour on the hour from 8 a.m. on March 15, when the increase began, until 2 p.m. on March 16 with an interval of 6 hours. The result indicating that the flow of the predicted plume to the south-southwest direction at 8 a.m. on March 15 changed clockwise shows a similarity to the observation. At 2 p.m., the plume reached between Ono, Okuma-machi, and Yamada, Futaba-machi. The prediction lags about 2 hours from the actual movement. At 8 p.m., the predicted plume passed near Namie, which almost coincides with the actual observation. After that, the movement reversed at around 2 a.m. on March 16 to pass near Yamada, Futaba-machi, with lags of about 2 to 3 hours from the actual observation. Although this is not shown in the figure, the lag was compressed by the time the plume reached Matsudate, Naraha-machi, before moving offshore at 8 a.m. The plume predicted at 2 p.m. reproduced the temporal increase in the dose rate in the southwest with a time lag of about 2 hours. This plume later moved offshore. Here, the figure corresponding to the period from 1 to 2 p.m. on March 16 presents a broader area in accordance with the expanded range of computation. The black-rimmed circles represent a range of 30 km from the center of the site.

On March 12, 15, and 16, the wind directions changed abruptly in a complex manner. However, the abovementioned results demonstrate that SPEEDI managed to provide a spatial-temporal overview of the movements of the radioactive plumes over time if we allow for a time lag of a few hours. The ICANPS report concluded that the predictions produced by SPEEDI for the north-west of the site could have been applied in deciding the timing of the sheltering on March 15 and the evacuation on March 16. The predictions were probably accurate enough for such an application.

Examples were not presented for March 13 and 14 because the plumes had moved offshore, making verification impossible. Nevertheless, SPEEDI also provided some useful information for these 2 days considering the successful prediction of the temporal increase in the coastal area and no major increases in the inland area.

Meanwhile, reduced accuracy was observed in some cases. From dawn throughout the rest of the morning on March 12 and 13, the release probably took place near the ground under almost calm weather conditions. With no definite wind directions, relatively small increases in the dose rate were observed in various directions near the site. Such a situation could not be properly predicted.

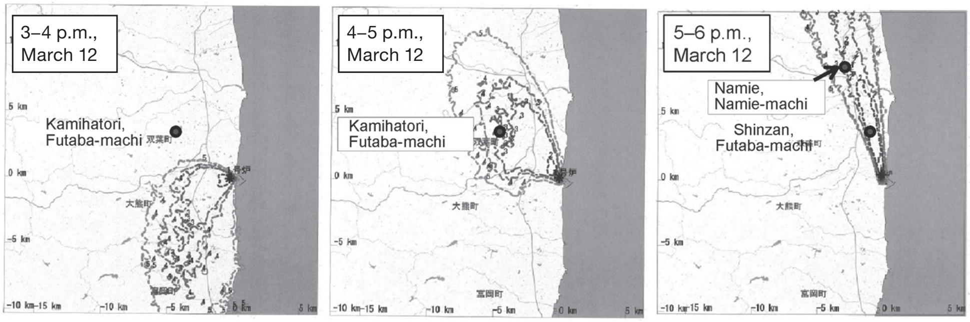

Figure 2 Regular predictions for the distribution of the air-absorbed dose rate 2 hours after the releases at 2, 3, and 4 p.m. on March 12
Source: http://www.bousai.ne.jp/speedi/20110312 rok/20110312.html

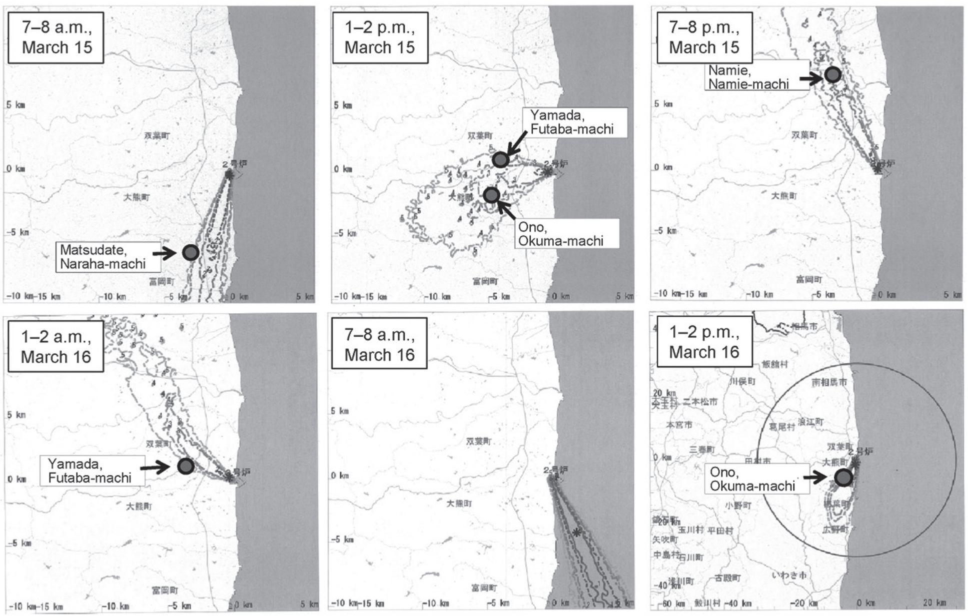

Figure 3 Regular predictions for the distribution of air-absorbed dose rate from March 15 to 16
Source:
March 15 http://www.bousai.ne.jp/speedi/20110315 rok/20110315.html
March 16 http://www.bousai.ne.jp/speedi/20110316 rok/20110316.html

In conclusion, SPEEDI should be utilized in predicting the arrival of a plume while allowing for certain margins of spatial-temporal error rather than expecting pinpoint information in terms of time and space. Margins of error depend on weather conditions and other factors. Accordingly, the predicted results should be adjusted in real time based on measurement data with a proper understanding of the relationship between SPEEDI's accuracy and weather conditions.

3. Accuracy and Timeliness of On-Demand Predictions

(1) On-demand predictions for the ERC [3)]

As no information on releases was available during the accident, the absolute values of the predictions produced by SPEEDI were not particularly meaningful. This commentary evaluates the predicted relative impact distribution.

Venting at Unit 1 on March 12: Prior to the venting conducted at Unit 1 from 2 p.m., the ERC requested on-demand predictions to check the impact by the venting. They received the results by 13:42. SPEEDI transmitted the distribution of the effective dose rate due to external exposure 3 hours after the release, as shown in **Figure 4** (a). The distribution corresponding to the venting from 2 p.m. may be slightly displaced in a southward direction because the pressure dropped at around 14:30, which is believed to be when the release actually began. However, SPEEDI successfully predicted the dose increase in the direction toward Kamihatori, Futaba-machi, which actually experienced the increase at 3 p.m. This demonstrates that the predictions produced by SPEEDI can offer an effective means of determining the range of impact prior to a planned release (e.g., venting).

Hydrogen explosion at Unit 1 on March 12: Following the hydrogen explosion that occurred at 15:36, the ERC requested computational predictions to assess the impact. They received the results by 16:49. For some unknown reason, the starting time for the release was set to 5 p.m. for the prediction. SPEEDI transmitted the distribution of the effective dose rate due to external exposure 3 hours after the release, as shown in Figure 4 (b). The prediction was provided with a sufficient degree of accuracy before the dose rate really increased in the direction of Namie-machi at 5 p.m. and in the direction of Minamisoma between 7 and 8 p.m. During the event, no environmental monitoring data was available, but the predictions produced by SPEEDI could have facilitated decision-making with respect to sheltering or other precautionary measures against risks associated with the massive release resulting from the hydrogen explosion.

Massive release on March 15: Following the sound of the explosion that was heard at around 6 a.m. on March 15, the ERC requested computational predictions to assess the impact of the damage that was assumed to have occurred at the suppression chamber of Unit 2. They received the results at 6:51. SPEEDI transmitted the distribution of the deposition of iodine on the ground surface over a period of 24 hours starting from 9 a.m. on March 15, as shown in Figure 4 (c). Figure 4 (c) demonstrates that SPEEDI had already predicted in the morning of the same day the level of ground surface contamination that would exist in the northwest area in the evening. At the site boundary, a high dose had been recorded since early morning on March 15. If there were concerns that the contamination might continue until the evening, there should have been sufficient time to make the necessary precautionary decision for the public in the northwest area.

Compared to regular predictions, on-demand predictions produce a better match with the actual measurements. This is because they require the amount of cumulative deposition and the dose distribution to assess the dose impact and, consequently, spatial-temporal errors are

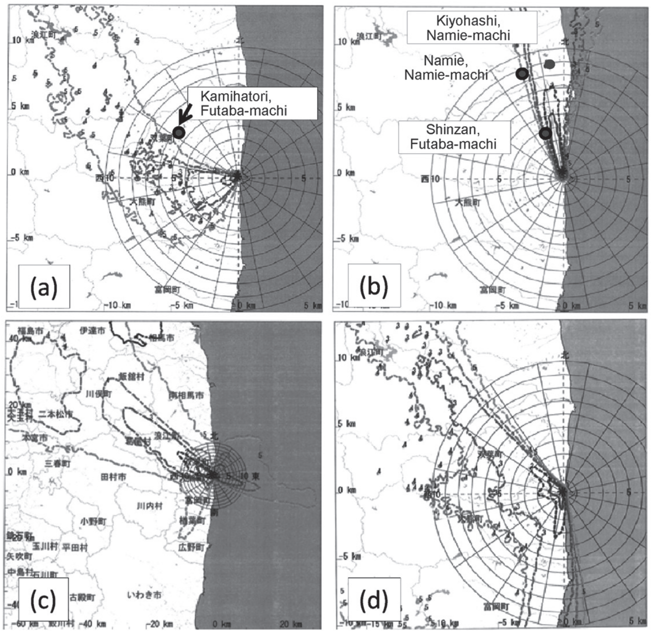

Figure 4 Examples of on-demand predictions
(a) Predicted impact of the venting on March 12 between 2 and 3 p.m.
(b) Predicted impact of the hydrogen explosion on March 12 at 15:36
(c) Predicted impact after the sound of the explosion on March 15 at around 6 a.m.
(d) Predicted impact for the planning of monitoring on March 15
Source:
(a), (b), (c) http://www.nsr.go.jp/archive/nisa/earthquake/speedi/erc/speedi_erc_index.html
(d) http://www.nsr.go.jp/archive/nisa/earthquake/speedi/ofc/speedi_ofc_index.html

canceled out through integration. In contrast, these errors appear in regular predictions due to the need to predict temporal changes of the plume.

(2) On-demand predictions for the OFC [4)]

The OFC has been receiving 24-hour predictions produced by SPEEDI by assuming a daily release of a unit quantity from March 14 as reference for the planning of emergency monitoring. When systematic emergency monitoring was initiated on March 15, the OFC received the distribution map for the effective dose rate due to external exposure before dawn at 2:32 on the same day as that shown in Figure 4 (d). This figure predicts the increase in the dose rate to the south of the site from dawn until late morning and to the northwest of the site in the evening. The prediction almost matched the actual measurements. As evidence of the effective utilization of SPEEDI, the investigation report (Chapter 2) [5)] published by MEXT mentions that the prediction produced by SPEEDI made it possible to immediately deploy a monitoring team to the northwest high-dose area. However, as information on the changing behavior of the plumes is also effective for enabling dust sampling to measure their atmospheric concentration, such predictions should also be provided by SPEEDI.

(3) On-demand predictions for the now defunct NSC [6)]

The NSC was unable to obtain information on the source term through the emergency response support system (ERSS). Accordingly, to evaluate the exposure dose for local residents by using SPEEDI, the NSC has since March 17 been inversely estimating the temporal variation of the release amount based on the monitoring results and predicted information produced by SPEEDI. On March 23, the thyroid dose of radioiodine was evaluated and the results were utilized to select target areas for examining children for thyroid exposure.

The reverse estimation of the source term was performed due to a lack of data from the ERSS. However, it has not been verified whether quantitatively reliable results could be obtained using the functional ERSS in combination with SPEEDI. Thus, rather than conducting a quantitative assessment based on the ERSS, which has uncertain reliability, and a forecast produced by SPEEDI, other dose assessments based on a simple fitting of the monitoring data with the computational predictions as well as dose assessments based on the reverse estimation of the source term may prove more useful even if the assessment is made in near real-time or hindcast.

III. Possible Utilization in the Future

Before the main discussion, we summarize the circumstances during the accident. Venting operations began at Unit 1 about 18 hours after the earthquake, while Unit 1 experienced a hydrogen explosion about 24 hours after the earthquake. These intended or unexpected atmospheric releases took place during the evacuation of nearby residents. Meanwhile, the systematic implementation of emergency monitoring had to wait for 4 days until March 15. Soon after the earthquake, SPEEDI was started up on March 11 as the only source of timely information for making decisions concerning countermeasures and establishing plans for monitoring. Despite the prediction for the relative distribution demonstrating a certain degree of reliability as explained above, SPEEDI could not identify absolute values and provide sufficient information.

Given these circumstances, it is unlikely that monitoring or computational predictions alone could provide a necessary and sufficient amount of the information required to deal with any emergency from its onset, no matter how much quicker the emergency monitoring and inverse estimation of the source term could be performed. Comprehensive assessments should be strengthened by combining mutually complementary monitoring and computational predictions.

In light of the verification provided here, computational predictions can be utilized in the following ways by realizing their capacity to provide forecasts and immediately assess the overall situation.

(1) In the initial stage before an emergency monitoring system has been properly set up:

- Planning of emergency monitoring and evaluation of monitoring results based on the predicted atmospheric dispersion and ground deposition.
- Early-stage decision-making with regard to the necessary measures based on an assessment of the current situation by fitting the discrete monitoring values and a predicted distribution that assumes the release of a unit amount.
- Judgment concerning the timing of evacuations, sheltering, ingestion of stable iodine tablet, and the like based on prediction for incoming plumes.
- Judgment concerning the timing of venting and other planned releases based on the impact prediction.

(2) Once an emergency monitoring system is in place:

- Evaluation of the scale of the accident by reverse estimation of the source term and detailed exposure dose assessment.

- Food inspection based on prediction for an extensive dispersion and facilitation of the surrounding communities to understand the processes by which hot spots are created.

Experts should be trained and become competent in both monitoring and computational predictions so that they can integrate their outcomes and extract useful information.

This commentary verifies the accuracy and timeliness of predictions produced by SPEEDI. It also proposes possible utilization for SPEEDI. The author hopes that the conclusions of this commentary will serve as a useful reference for the national and local governments when they draft manuals and other documents on nuclear emergency measures.

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Decontamination Measures for Fukushima Prefecture

−Fukushima Prefecture Measures for Promoting Decontamination−

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Fukushima Prefecture is still saddled with a huge number of problems due to the damage caused by the Fukushima Daiichi Nuclear Power Plant Accident in the aftermath of the Great East Japan Earthquake. One of the most pressing tasks that it faces is to carry out decontamination work for the radioactive materials released during the accident. This commentary explains how the prefectural government of Fukushima is currently assisting municipalities to facilitate this decontamination work through three main pillars of activities: (1) accelerating the training of operators and other staff; (2) boosting technical assistance; and (3) promoting understanding (and participation) among local residents.

I. Current Situation in Fukushima Prefecture

At present, 40 municipalities in the prefecture have been designated by the Ministry of the Environment (MOE) as intensive contamination survey areas. These municipalities have an average hourly radiation dose of at least 0.23 μSv (1 mSv per year), but municipalities that have been designated as special decontamination areas (i.e., areas in which decontamination work is conducted by the national government) are excluded. Of these 40 municipalities, 36 have already developed decontamination plans. The remaining four municipalities, which have a relatively low dose, are considering whether they should formulate such plans despite having been designated as intensive contamination survey areas (**Figure 1**).

II. Framework for Facilitating Decontamination

In intensive contamination survey areas, municipalities have been taking a leading role in the conducting of decontamination work following the full enforcement of the Act on Special Measures Concerning the Handling of Pollution by Radioactive Materials on January 1, 2012.

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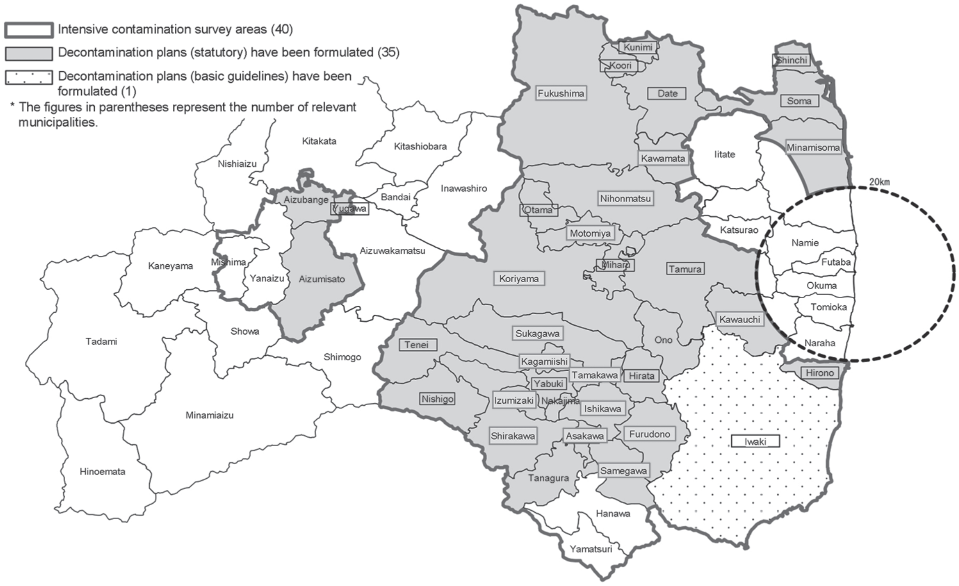

Figure 1 Municipalities designated as intensive contamination survey areas pursuant to the Act on Special Measures and the status of their decontamination plans

To facilitate this work, the prefectural government has established three main pillars of activities: (1) accelerating the training of operators and other staff; (2) boosting technical assistance; and (3) promoting understanding (and participation) among local residents.

1. Accelerating the Training of Operators and Other Staff

The training of operators is imperative for full-fledged decontamination efforts. The prefectural government of Fukushima organizes workshops (**Figure 2**) to allow those engaged in decontamination work to acquire the basic knowledge and skills required.

In FY2011, 15 workshops were held for more than 3,300 trainees from October 2011 to March 2012. In addition, 32 workshops on radiation and decontamination were held in the relevant areas for more than 2,000 leaders of the radiation measurement and decontamination activities.

From FY2012, decontamination workshops were expanded to offer three courses. The first course was held for those actually performing the decontamination work in the same manner as the workshops held in FY2011. In Fukushima Prefecture, 4,443 decontamination workers completed this course.

The second course was held for the on-site leaders and supervisors of decontamination work. This training course was completed by 1,913 people.

The third course was held for operational managers in light of the shortage of supervisors with specialized knowledge. The 1,390 people who completed this training course will assist in supervising any decontamination work that is outsourced by the municipalities.

Training courses for personnel involved in decontamination work will also be held in FY2013.

Figure 2 Attendees at a decontamination workshop

Figure 3 Demonstration of a decontamination technology

2. Boosting Technical Assistance

(1) Technical demonstrations

Technical demonstrations have been held since FY2011 to promote the development of more effective and efficient technologies. To this end, the prefectural government issues calls for proposals from the private sector, universities, research institutes, and so forth. The prefectural government evaluates their technologies by comparing the radiation dose before and after the decontamination work was conducted (**Figure 3**). In FY2011, 20 of the 177 proposed projects were selected for field trials. The results were announced in March 2012. In FY2012, two calls for proposals were issued. For field trials, 12 of the 98 proposals were chosen in the first round and six of the 32 proposals were chosen in the second round. Technical demonstrations will also be conducted in FY2013. To encourage the application of more effective and efficient decontamination technologies, the prefectural government subsidizes the costs incurred by municipalities in the conducting of demonstration tests to explore new decontamination technologies and methods.

(2) Technical guidelines for decontamination work

Examples of the contracting procedures for the outsourcing of decontamination work were compiled in December 2011. In January 2012, technical guidelines for decontamination work were developed as a compilation of the specific steps, methods, management standards, and all other requirements that apply to decontamination sites.

Samples of common templates for decontamination work were prepared in July, while samples of estimation standards for decontamination work were prepared in August. These samples were subsequently provided to the relevant municipalities.

These documents will be revised to help municipalities outsource decontamination work and manage its implementation.

(3) Decontamination Information Plaza

In January 2012, the prefectural government established the Decontamination Information Plaza, which is jointly operated with the MOE's Fukushima Office for Environmental Restoration. The Decontamination Information Plaza provides information on decontamination matters in partnership with the Japan Atomic Energy Agency (JAEA) and the Atomic Energy Society of Japan (AESJ). Such information includes details on the latest technologies and equipment as well as the progress made in decontamination work.

The Decontamination Information Plaza uses intuitive exhibits to explain decontamination. It also holds symposiums and workshops for children and their parents to gain a wider public understanding of the impact of radioactivity and the necessary countermeasures.

Furthermore, about 80 volunteer experts are registered with the Decontamination Information Plaza. These experts are dispatched as necessary to offer technical advice to municipalities.

3. Promoting Understanding among Local Residents

(1) Community discussion forums

The understanding of Fukushima Prefecture residents is vital for the conducting of decontamination work. Therefore, the prefectural government has been working with the AESJ since FY2011 to hold forums in many places with the aim of promoting greater understanding of radiation and decontamination.

Each forum consists of lectures and discussion sessions. Participants are invited to exchange their views on how the decontamination work is being conducted and how their health is being affected.

The first forum was held in November 2011. In total, four forums were held in various parts of Fukushima Prefecture in FY2011 and a further five forums were held in FY2012.

The prefecture also supports the briefing sessions that municipalities hold for residents by dispatching experts.

(2) Study tours of temporary storage yards

For progress to be made in decontamination work, temporary storage yards are needed for the storage of removed soil and other waste. However, securing such space can prove problematic due to a lack of understanding from local residents. One of the main reasons for this is concerns over the safety of temporary storage yards. Accordingly, the prefectural government has been conducting study tours since July 2012 in collaboration with the JAEA and municipalities that have already established such yards. In these hands-on study tours, visitors get to learn how these yards are structured, maintained, and managed. They can also measure the air dose rate for themselves (**Figure 4**).

The prefectural government also supports the briefing sessions that municipalities hold for residents by dispatching experts.

Figure 4 Staff conduct dose measurements during a study tour at a temporary storage yard

(3) Assistance in reducing the radiation dose

The prefectural government subsidizes the costs incurred by neighborhood associations, parent teacher associations, and other community-based organizations in conducting voluntary activities to reduce radiation dose for children on their ways to schools, as well as in parks and other spaces they usually spend time. Examples of such activities include measuring the air dose rate and conducting spot decontamination of road ditches. In total, 3,091 groups from 44 municipalities benefited from such subsidies in FY2011, and 1,515 groups from 31 municipalities are expected to benefit in FY2012.

III. Progress Made in Decontamination Work and Challenges Ahead

1. Progress Made in Decontamination

As of January 2013, 35 of the 36 municipalities that had already formulated decontamination plans have outsourced decontamination work. A comparison with the planned numbers reveals that decontamination has been outsourced for 63,328 of the 80,419 houses, 3,475 of the 3,739 public facilities, 2,159 km of the 2,895 km of roads, 20,943 ha of the 25,845 ha of farmland, and 739 ha of the roughly 4,090 ha of forests in living areas.

2. Decontamination Efforts by Municipalities and Challenges Ahead

(1) Securing space for temporary storage yards

One major obstacle to conducting decontamination work is the difficulty involved in securing space for temporary storage yards. The prefectural government aims to dispatch experts and personnel to hold briefing sessions for local community members in an effort to gain their understanding. Furthermore, to establish more temporary storage yards, the prefectural government will work with municipalities to present examples of advanced solutions and conduct study tours.

(2) Assistance for municipalities in outsourcing decontamination and related work

Among the other challenges that they face, municipalities have a shortage of personnel with specialized knowledge in relation to the outsourcing and supervising of decontamination work. To address this challenge, the prefectural government will prepare samples of standard templates and estimation standards for the outsourcing of decontamination work, revise their technical guidelines as necessary, continue to hold briefing sessions and offer on-site counseling services, train supervisors at decontamination workshops, and dispatch trained experts.

(3) Training and recruitment of decontamination operators

As the decontamination work conducted by the respective municipalities gathers pace, there are growing concerns about the shortage of decontamination operators. Therefore, the prefectural government will continue to hold decontamination workshops to train more decontamination workers and supervisors. It will also help facilitate cooperation among local operators to increase their decontamination capacity and workforce.

(4) Swift and flexible provision of decontamination subsidies

During the ongoing decontamination work, the methods specified in the guidelines issued by the national government have often proven unable to reduce the radiation dose as expected. Although more effective methods are required, preferential financial measures only support the methods specified in the national guidelines or methods that have been approved after consultation with the national government. To facilitate progress in the decontamination work, the prefectural government will strive to establish a more flexible subsidy system to promote the use of proven decontamination methods according to local realities.

3. Conclusions

Almost 2 years have passed since the accident occurred on March 11, 2011. Decontamination work has been conducted through a process of trial and error, but this work must be accelerated to support early recovery and reconstruction. We would like to express our deep gratitude for the many different types of assistance that we have received from various people throughout the country to date and for all future assistance.

Atmospheric Dispersion Simulations for the Assessment of Radiological Dose to the Public

−Reassessment of the Atmospheric Concentration Distribution of Radioactive Materials in the Immediate Aftermath of the Accident at the Fukushima Daiichi Nuclear Power Plant−

Japan Atomic Energy Agency, **Haruyasu Nagai**

Radioactive materials were released into the environment due to the accident that occurred at the Fukushima Daiichi Nuclear Power Plant, which is operated by the Tokyo Electric Power Company. This release immediately led to the performance of an internal exposure dose assessment of iodine and other nuclides with a short half-life. To determine the necessary dose estimation, the spatial-temporal distribution of the atmospheric concentration of radioactive materials was reassessed by performing dispersion simulations with ^{131}I, ^{133}I, ^{132}Te, and ^{137}Cs with due consideration given to their contribution to the internal exposure doses. A database of the spatial-temporal distribution of the concentration was developed based on the results obtained from the calculations performed for each defined time at a horizontal interval of 3 km near the ground surface.

I. Introduction

Radioactive materials were released into the environment due to the accident that occurred at the Fukushima Daiichi Nuclear Power Plant, which is operated by the Tokyo Electric Power Company (TEPCO). The exposure doses must be tracked as they serve as basic data for assessing the health risks faced by local residents of Fukushima Prefecture and its surrounding areas. At present, it is difficult to perform an assessment of the internal exposure doses for iodine and other nuclides with a short half-life based on measurements during the initial post-accident phase. A realistic approach to determining the necessary estimation is to combine a behavior pattern and a chronological atmospheric concentration map of the radioactive materials from an atmospheric dispersion simulation. The Japan Atomic Energy Agency (JAEA) is conducting a detailed analysis of the transport of the nuclear materials released into the environment due to the accident [1-4] by employing the System for Prediction of

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Environmental Emergency Dose Information (SPEEDI), which was developed for responding to nuclear emergencies, and the worldwide version of SPEEDI (WSPEEDI)[5].

This commentary explains how WSPEEDI was employed in the detailed atmospheric dispersion analysis of the radioactive materials released into the environment due to the Fukushima Accident. The analysis performed using atmospheric dispersion simulations was intended to develop a spatial-temporal distribution database of the atmospheric concentration of radioactive materials, which is needed for the dose estimation.

II. Analysis Method

1. Source Conditions

In preparation for atmospheric dispersion simulations, temporal changes in the release rates for iodine and other nuclides with a short half-life, the release heights, and other source conditions (source term) were investigated and compiled based on open information and publications. These factors were organized as input conditions for performing the simulations. To validate the results produced by these atmospheric dispersion simulations, the source conditions for conducting simulations of ^{137}Cs and other nuclides with a long half-life, for which a relatively abundant amount of local measurement data is available, were also prepared. More specifically, the JAEA has published papers in scientific journals to present the estimated sources of ^{131}I and ^{137}Cs based on a combined analysis conducted using both atmospheric dispersion simulations and monitoring data[1-4]. These estimated sources are the only estimation results that accommodate changes to the settings for the release rate during the target period and enable the reproduction of environmental monitoring results. These results were then compared with other estimation results as well as the results of an analysis of the reactor interiors to closely examine the source conditions and prepare the input conditions for simulations.

2. Atmospheric Dispersion Analysis

The atmospheric dispersion simulations were conducted by reproducing the meteorological field that existed during the accident in a three-dimensional meteorological model and subsequently calculating the transport, dispersion, and deposition of radioactive materials based on the abovementioned source conditions. The analysis was carried out using the meteorological model MM5 and the atmospheric dispersion model GEARN of WSPEEDI[5], which was developed by the JAEA.

The meteorological model MM5 calculates the three components of wind speed, turbulence quantities, and precipitation as well as other meteorological factors that are needed to calculate the atmospheric dispersion based on numerical forecast data provided by the Japan Meteorological Agency and other initial conditions. This model numerically solves the equations for the three momentum components that take into consideration the spherical effect of the Earth and topographical influence as well as factors such as thermal energy, the water vapor quantity, and the cloud water content (liquid and solid). The atmospheric dispersion model GEARN derives the atmospheric concentration of radioactive materials and the quantity deposited on the ground surface by calculating the transport and dispersion of these materials based on the source conditions and meteorological factors obtained using the meteorological field calculation. This model also calculates the air dose rate based on the atmospheric concentration of radioactive materials as well as air dose rate affected from the radionuclides deposited on the ground surface. Given the need to produce a precise evaluation of the radiation impact caused by a localized high-concentration distribution near the source, GEARN employs a Lagrangian particle dispersion model to take into consideration attenuation by the radioactive decay of the respective released nuclides. On the ground surface, both dry deposition due to turbulent flow and wet deposition due to precipitation are taken into consideration. The calculation of the wet deposition takes into account the three-dimensional distribution of precipitation and cloud cover derived from the three-dimensional meteorological model. The precision of these models has been verified by the Chernobyl Accident analysis, and real-time predictions and performance assessment of post-test analysis conducted in the European Tracer Experiment.

The exposure dose assessment targets onshore areas within 250 km of the source. Accordingly, the atmospheric concentration and other factors considered in atmospheric dispersion simulations were calculated over an area extending 690 km east-west and 960 km north-south with a horizontal spatial resolution of 3 km. The behavior of the radioactive materials released into the atmosphere within the target period from 0:00 on March 11 to 24:00 on April 30, 2011, was continuously calculated.

III. Analysis Results

1. Source Conditions

Calculations were performed with ^{131}I, ^{133}I, ^{132}Te, and ^{137}Cs, taking into consideration their contribution to the internal exposure doses based on the estimated source term. The amount of ^{137}Cs was also used in a comparison with measured data on the deposition quantity. The time variations of the release rate were used by those estimated by the JAEA for ^{131}I and ^{137}Cs (**Figure 1**)[4]. For other nuclides with a short half-life (^{133}I and ^{132}Te) the radioactivity ratio to ^{131}I and ^{137}Cs were estimated based on the limited environmental monitoring data, decay coefficients, and estimated inventory.

Figure 2 compares the radioactivity ratio in the inventory for each time of release with the ratio of radioactivity according to data from the atmospheric concentration measurements. Based on nuclide characteristics, the condition of ^{132}Te in the atmosphere is presumably similar to that of ^{131}I. However, the ratio of ^{132}Te to ^{131}I in a dust sample demonstrates a low

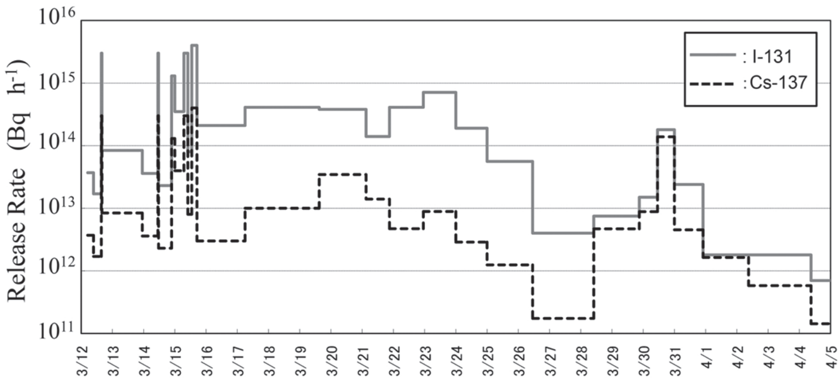

Figure 1 Time variation of release rates for ^{131}I (solid line) and ^{137}Cs (dashed line)

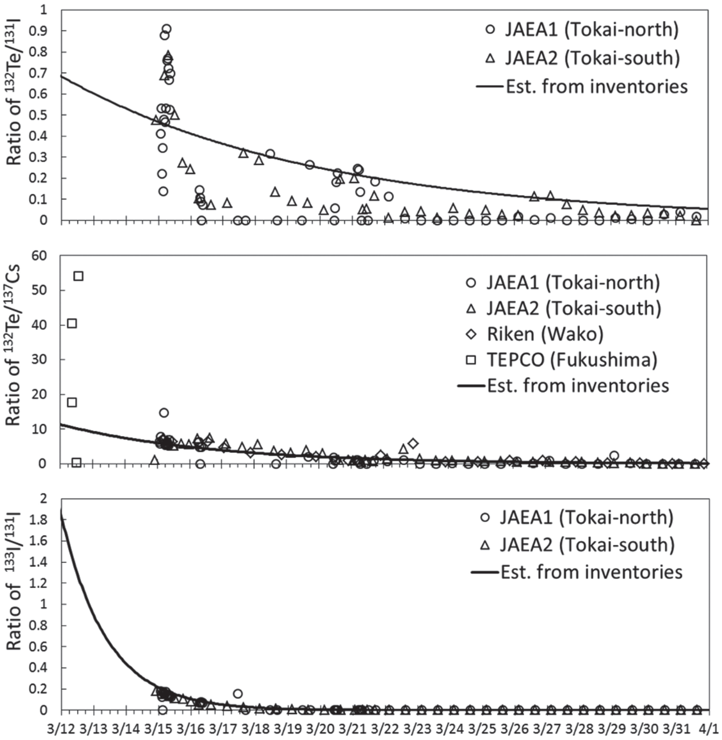

Figure 2 Comparison of time variation of radioactivity ratio of ^{133}I and ^{132}Te to ^{131}I or ^{137}Cs (○, △, ◇, and □ indicate the radioactivity ratios from the dust sampling, while solid lines represent the radioactivity ratios estimated from the inventory)

correlation with the ratio of radioactivity in the inventory during the release. Meanwhile, strong correlations can be observed with respect to the radioactivity ratio of ^{132}Te to ^{137}Cs from the dust sample and those from the inventory during the release. Adjusting the radioactivity ratio for the initial inventory to ^{132}Te/^{137}Cs = 20 produced a satisfactory reproduction of the radioactivity ratio in the dust sample with the radioactivity ratio in the inventory during the release. The behavior of ^{133}I during its release and atmospheric dispersion is assumed to be the same as that of ^{131}I. In the dust sample and inventory, changes in the radioactivity ratio almost overlap each other. Accordingly, the radioactivity ratio of ^{133}I to ^{131}I can probably be adopted directly from the ratio in the inventory during the release.

The abovementioned changes in the release rate for each nuclide were assigned as the basic source conditions to investigate their uncertainty ranges and the resultant impact on the calculation of the concentration. The source term estimation result produced by the JAEA to assign temporal changes in the release rate for ^{131}I and ^{137}Cs has already been verified through a comparison with some reproductive tests that were conducted using environmental monitoring data based on a simulation of the atmospheric dispersion and an estimation of the release rates by Japanese and overseas research institutes. A comparison with the estimates [6] produced by Hirao et al. from Nagoya University demonstrated almost the same changes over time. Hirao et al. have also evaluated the uncertainty associated with the estimated release rates and concluded that the estimated values have a range with a factor of 3 (ranging from 1/3 to 3 times). Similar to the JAEA, Hirao et al. adopted a method of deriving a release rate that reproduces the environmental monitoring data by means of an atmospheric dispersion simulation. As they commonly employ similar atmospheric dispersion models, the estimates produced by the JAEA were assumed to have a range with a factor of approximately 3 to assess the impact of uncertainty associated with the source information.

2. Atmospheric Dispersion Analysis

Based on the abovementioned source conditions, the predicted accuracy was evaluated by comparing simulations produced by using WSPEEDI and the actual measurements for the air dose rates, the airborne nuclide concentration, and the distribution of the ^{137}Cs deposition.

To address the process involved in the dispersion of released radioactive materials in the atmosphere and the contamination of the ground surface, the JAEA held an open workshop on March 6, 2012 entitled “Reassessment of the environmental release and dispersion process associated with the accident at the Fukushima Daiichi Nuclear Power Plant.” Based on the discussions with participants from other organizations, the key plume movements and the deposition process that formed the deposition distribution of ^{137}Cs as observed by aircraft monitoring were summarized as follows.

(1) March 12: The plume passed Minamisoma in the direction of the sea and then passed through the environs of the Onagawa Nuclear Power Plant, causing dry deposition in these areas.

(2) March 15: The plume released before dawn travelled southward along the coast, causing dry deposition in the area located between Iwaki and northern Ibaraki.

(3) March 15–16: The same plume moved inland from Ibaraki on the Kanto Plain, causing wet deposition in Gunma Prefecture and Tochigi Prefecture. The plume released before noon traveled southwest and west, causing wet deposition in Nakadori, Fukushima Prefecture. A highly concentrated plume released in the afternoon was carried northwest from the nuclear power plant, causing wet deposition to form a highly contaminated area.

(4) March 20: The plume moved northeast after flowing northwest, causing wet deposition while passing through the area between northern Miyagi and southern Iwate.

(5) March 21: The plume traveled southward over the sea, causing wet deposition while passing through the area between southern Ibaraki and northwestern Chiba to form a hot spot.

Based on these results, an evaluation was conducted to assess the reproducibility of the plume movements and the associated deposition.

As an example, **Figure 3** compares the time variations of the calculated and measured air-absorbed dose rates during Event (2) at the Fukushima Daini Nuclear Power Plant, Iwaki, Kitaibaraki, and Mito. This comparison presents not only computational grids that correspond to the observation points, but also grids within 3 km or 9 km of the observation points. The reproducibility of the measurements is significantly compromised if the course taken by the plume deviates even slightly in a comparison with spatially discrete measurement data. Therefore, the comparison in Figure 3 is intended to gauge the extent of the misalignment in such cases. Changes at each of the points in eastern Japan were almost reproduced, but there were two- to three-hour misalignments in the timing of the plumes as they passed over some points depending on the periods and areas. In some cases, the plumes passed a few meshes apart. An exposure dose assessment based on an atmospheric dispersion simulation needs to take into consideration the uncertainty associated with such spatial-temporal misalignments of the passing plumes.

With respect to the time histories of airborne nuclide concentration, **Figure 4** compares the calculated and measured atmospheric concentration of ^{131}I when plumes passed over Tokai-mura (JAEA) from March 14 to 17 and 20 to 21. Although the reproducibility of the time variations was similar, some cases of quantitative underestimation imply that the

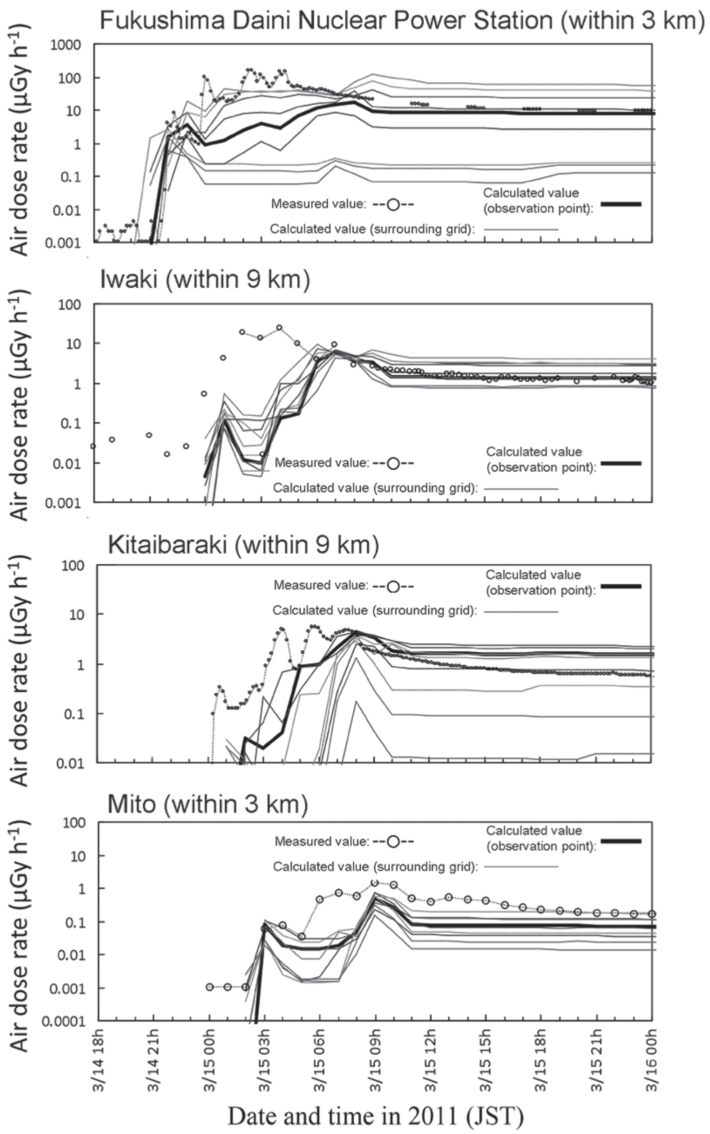

Figure 3 Comparison of measured and calculated air-absorbed dose rates when a plume passed over the Fukushima Daini Nuclear Power Station (Plant), Iwaki, Kitaibaraki, and Mito on March 15 (The calculated values correspond to the grids covering the observation points and the grids within 3 km or 9 km of these points)

uncertainty associated with the source conditions had an impact.

Compared with the distribution measured by aircraft monitoring, WSPEEDI overestimated the deposition of ^{137}Cs in Miyagi Prefecture and underestimated it in Gunma and Tochigi Prefectures. This is probably attributable to the application of the uniform precipitation scavenging rate without taking into consideration vertical variations in the conditions for the wet deposition process. The reproducibility improved when the following factors were taken into consideration: the actual weather that prevailed during the accident; differences in the scavenging rates in the ice and liquid phases as well as inside and under the clouds; and the impact from fog deposition. The impact assessment is being conducted through an analysis that

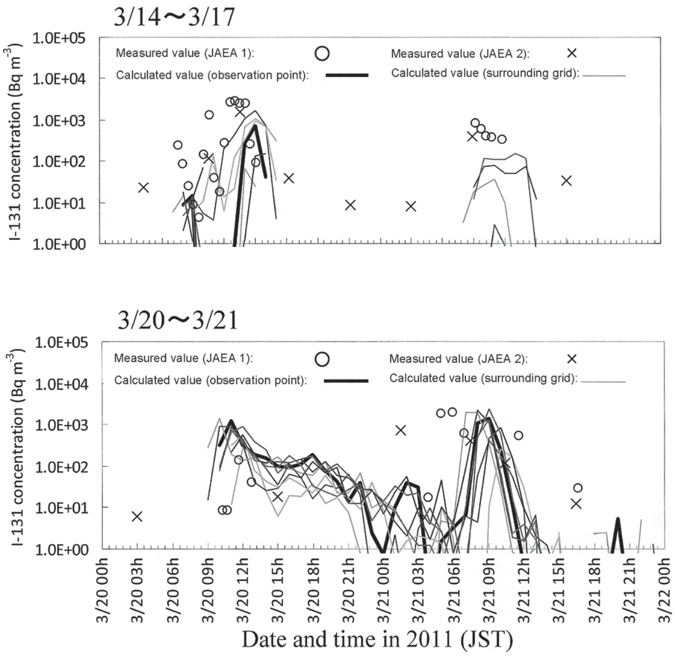

Figure 4 Comparison of the measured and calculated atmospheric concentration of ^{131}I when the plumes passed over Tokai-mura (two observation points at the JAEA) from March 14 to 17 and 20 to 21 (The calculated values correspond to the grids covering the observation points and the grids within 18 km from there)

takes into consideration differences in the dry deposition velocity and the scavenging rate depending on the forms of the airborne nuclides.

The uncertainty associated with the source conditions and the atmospheric dispersion simulations must be addressed to perform more precise exposure dose assessments. The source conditions are inversely estimated from the measured radioactive nuclide concentration through atmospheric dispersion simulations. Given this, the source conditions are influenced by the uncertainty associated with the model calculations. Because the simulations are based on spatially and temporally discrete measurement data, uncertainty is further compounded by the use of an interpolation method and the assumptions made in calculating the dispersion, such as the release height and duration. To address this uncertainty, it is necessary to enrich the measurement data and conduct an analysis again using an improved model. However, improvements to the model crucially require a comparison of the calculations based on accurate source conditions and measurement data. Going forward, we need to establish an analysis method that meets these almost contradictory requirements.

3. Impact of Modifications to the Deposition Process

The possibility of improving reproducibility of the distribution of the ^{137}Cs deposition by aircraft monitoring was demonstrated after modifications had been made to the deposition process in the dispersion calculation. Accordingly, the degree of its impact was investigated on the calculation of the atmospheric nuclide concentration near the ground used for an internal exposure dose assessment. More specifically, the integrated atmospheric concentrations near the ground surface were compared to evaluate the maximum extent of the impact by examining the following: the difference between cases with completely gaseous radioactive nuclides and cases with completely particulate nuclides; the difference observed with one-tenth of the scavenging coefficient in the ice phase; and the difference between cases with the maximum and minimum scavenging coefficients for particulate nuclides.

The transition of completely gaseous radioactive nuclides into completely particulate nuclides caused a significant increase in the deposition quantity and the integrated atmospheric concentration near the ground surface. Given that radioactive nuclides in the atmosphere are removed due to deposition, the increased removal quantity and the increased atmospheric concentration seem contradictory. Nonetheless, this result is valid. It can be explained by the difference in the deposition processes and the three-dimensional distribution of the removal quantity. With the parameters applied on this occasion, the dry deposition velocity is six times higher with completely gaseous radioactive nuclides than it is with completely particulate nuclides. However, the precipitation scavenging coefficient is lower with completely gaseous radioactive nuclides than that with completely particulate nuclides. Hence, when completely gaseous radioactive nuclides are replaced by completely particulate nuclides, they experience significantly less dry deposition and an increased level of wet deposition. In other words, wet deposition results in a large deposition quantity as clouds and precipitation removes radioactive nuclides from the atmosphere at high altitudes. In contrast, dry deposition removes atmospheric nuclides near the ground surface, causing deposition. However, this is because the reduction in the concentration there becomes larger, although the deposition quantity may be small. Any change in the proportion of gaseous and particulate radioactive iodine causes a considerable change in the atmospheric concentration near the ground surface, thereby increasing the impact on an internal exposure dose assessment.

Modifying the scavenging coefficient in the ice phase to 1/10 improved the overestimation of the ^{137}Cs deposition distribution in Miyagi Prefecture. However, the integrated atmospheric concentration near the ground surface barely changed. Since any change in the scavenging process in the ice phase affects only the cool parts of a plume at high altitude, the atmospheric concentration near the ground surface remained almost unchanged. For this reason, the enhanced reproducibility of the ^{137}Cs deposition distribution with a modified scavenging coefficient in the ice phase probably has little impact on an internal exposure dose assessment.

As you would normally expect, any difference between the maximum and minimum scavenging coefficients for particulate nuclides caused the integrated atmospheric concentration near the ground surface to increase as the deposition quantity decreased. In particular, the deposition quantity and the integrated atmospheric concentration near the ground surface changed significantly in areas with a predominant wet deposition when plumes passed during (3) March 15 to 16 and (5) March 21. Careful attention must be given to this point during an internal exposure dose assessment.

4. Time-Series Atmospheric Concentration Map of Radioactive Materials

A time-series atmospheric concentration map of radioactive materials was prepared by outputting the distribution of the atmospheric concentration near the ground surface and the ground surface deposition of each nuclide as calculated in the atmospheric dispersion simulation produced using WSPEEDI. The output was performed at a horizontal interval of 3 km in both the east-west and north-south directions every hour on the hour (average value in one hour). The calculation method was adjusted to output a database that facilitates the later assignment of source conditions after an atmospheric dispersion simulation has been performed using unit release conditions. In addition, databases were created for each case using the assigned parameters for gaseous and particulate materials based on analysis results that reflect the considerations taken with respect to the deposition process in the dispersion simulation described earlier. These cases could be combined to create dispersion analysis results for any proportions of gaseous and particulate materials.

To create each database with reference to the assigned changes in the release rate over time in Figure 1, a calculation is performed by assigning the unit release rate (1 Bq h^{-1}) of each nuclide for one segment (e.g., 30 segments, with the first segment lasting from 5 am to 9:30 am JST on March 12) at a constant release rate. Regardless of the availability of the calculated values for the atmospheric concentration and deposition, the followings are output at an interval of one hour throughout the target period: the calculated concentration, the deposition quantity, and the air dose rate of each nuclide. This calculation is performed for all 30 segments at a constant release rate. The outputs are stored as a database in a directory format

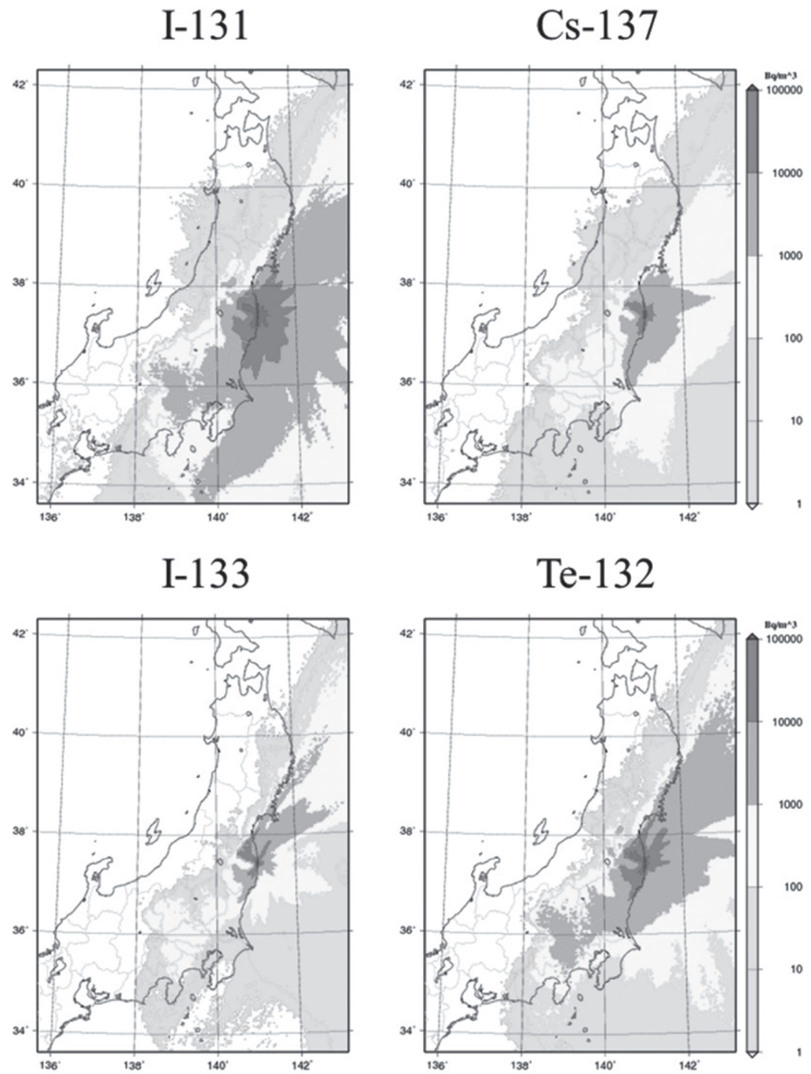

Figure 5 Integrated atmospheric concentration of ^{131}I, ^{133}I, ^{137}Cs, and ^{132}Te near the ground surface during the assessment period from 00:00 on March 11 to 24:00 on April 30, 2011

associated with each segment. To produce the calculation results for the source conditions assigned by the database, the release rate for each nuclide assigned to each segment at a constant release rate is multiplied by the outputs for the concentration, the deposition quantity, and the air dose rate of each nuclide for the entire period stored in the associated directory. Subsequently, outputs that correspond to the same time are combined. This method demonstrated an almost identical output as that for the dispersion simulations performed by assigning source conditions in the beginning.

This calculation method was employed to create databases for nine cases using different model parameters for gaseous and particulate materials. The results of the dispersion analysis can be produced for any proportion of gaseous and particular materials by combining the outputs from each case prepared by adjusting the source conditions.

Figure 5 shows the distribution of the integrated atmospheric concentration of each nuclide near the ground surface during the target period as prepared by applying the basic source conditions to these databases. The integrated concentration distribution varies according to different temporal changes in the release rate of each nuclide. In particular the distributions for ^{133}I and ^{132}Te with a short half-life indicate a large release rate in the immediate aftermath of the accident when the plume was being carried northeast.

IV. Conclusions

The Fukushima Daiichi Nuclear Accident immediately led to the performance of an internal exposure dose assessment of iodine and other nuclides with a short half-life from among the various radioactive materials released into the environment. To determine the necessary internal dose estimation, database for the spatial-temporal distribution of the atmospheric concentration of radioactive materials was constructed by performing dispersion simulations. The analysis results include uncertainty associated with the source conditions and the model calculation, but they can be applied to produce rough estimates of the dose. Nonetheless, they are not yet precise enough. The level of precision must be further enhanced by improving the model and scrutinizing the source conditions.

The analysis presented in this commentary was subcontracted by the National Institute of Radiological Sciences to develop time-series maps of the atmospheric concentration of radioactive materials through the performance of atmospheric dispersion simulations. This was done as part of an internal exposure dose assessment of iodine and other nuclides with a short half-life in the immediate aftermath of the nuclear accident under a project led by the Ministry of the Environment to assess the impact of the Fukushima nuclear emergency in FY2012.

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Commentary

Atmospheric Dispersion Simulations for Estimating Radiation Dose to the Public
–Reconstruction of Early Internal Dose to the Public in the TEPCO Fukushima Daiichi Nuclear Power Station Accident–

National Institute of Radiological Sciences, **Osamu Kurihara**

Given the limited availability of data from measurements conducted on affected people and the environment, atmospheric dispersion simulations played an essential role in estimating the early internal exposure doses for local residents affected by the accident that occurred at the Fukushima Daiichi Nuclear Power Plant (Station), which is operated by the Tokyo Electric Power Company. The estimates obtained from such simulations were also partially used in the previous fiscal year (2012), when the National Institute of Radiological Sciences reassessed the early internal exposure doses for residents of Fukushima Prefecture. This commentary describes the current status of, and future prospects for, internal exposure dose estimations produced by atmospheric dispersion simulations.

I. Introduction

Radioactive nuclides were released into the environment due to the accident that occurred at the Fukushima Daiichi Nuclear Power Plant, which is operated by the Tokyo Electric Power Company (TEPCO). These nuclides were dispersed across an extensive area throughout eastern Japan and beyond. Their deposition on the ground surface exposed the public to radiation. To date, there have not been any reported cases of the public being exposed to excessive radiation; however, it is important to assess the exposure doses for individuals accurately to facilitate discussions on how human health will be affected by radiation in the future. The prefectural government of Fukushima has been conducting a health management survey for all residents of the prefecture [1). The basic data incorporates estimated external exposure doses for individuals. These estimates are conducted by combining the time-series data for the places where each individual resided based on their activity records using a two-dimensional map developed based on air dose rate data obtained from actual measurements performed in different parts of Fukushima in the immediate aftermath of the accident. As an exception, for a period beginning from the day after the accident (March 12 to March 14, 2011), the estimate made use of values calculated using the System for Prediction of Environmental Emergency

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Dose Information (SPEEDI). The necessary set of calculations is conducted by using an external exposure dose assessment system [2] developed by the National Institute of Radiological Sciences (NIRS). To date, the NIRS has estimated the external exposure doses for over 400,000 residents of Fukushima Prefecture by using this system in collaboration with Fukushima Medical University [3].

Meanwhile, the internal exposure doses of individuals have been estimated based on measurements conducted in Fukushima and other parts of Japan by using whole body counters. Almost all of the more than 100,000 Fukushima residents who have already been tested had a dose of less than 1 mSv [4]. It should be noted that each estimated internal exposure dose was the committed effective dose associated with the body intake of radioactive cesium. Due to a lack of sufficient data from measurements conducted on people and the environment, detailed estimates have not been made for the internal exposure doses associated with radioactive iodine and other nuclides with a short half-life that were present in the immediate aftermath of the accident. In the case of the Fukushima Accident, it would probably be difficult to apply the method for reassessing the doses received by local residents affected by the Chernobyl Accident; i.e., the method for associating the amount of nuclides deposited on the ground surface with individual internal exposure doses [5]. The reasons why this would be difficult include the considerable fluctuations in the ratio of iodine to cesium deposited on the ground surface as well as the earlier outward evacuation of residents living within 20 km of the Fukushima Daiichi Nuclear Power Plant. Given these circumstances, an atmospheric dispersion simulation is considered the only remaining option for complementing the dose estimations with data from actual measurements. The exploration of this possibility is vital for reassessing the doses received by the public.

In the previous fiscal year (2012), the NIRS attempted to reassess the early internal exposure doses for residents of Fukushima Prefecture—with a particular focus on thyroid equivalent doses (hereinafter referred to as “thyroid doses”)—by combining the limited actual measurement data with atmospheric dispersion simulations [6]. The results are presented in **Table 1**. Partial reference was made to estimates from the atmospheric dispersion simulations. This commentary explains the background to this and describes the current status of, and future prospects for, early internal exposure dose estimations produced by atmospheric dispersion

Table 1 Estimated thyroid doses for residents of Fukushima Prefecture (90th percentile)

Municipality	Children aged one year	Adults	Reference data for dose estimate
Futaba-machi	30	10	Whole body counts
Okuma-machi	20	< 10	Whole body counts
Tomioka-machi	10	< 10	Whole body counts
Naraha-machi	10	< 10	Whole body counts
Hirono-machi	20	< 10	Whole body counts
Namie-machi	20	< 10	Whole body counts and thyroid measurements*
Iitate-mura	30	20	Thyroid measurements and whole body counts
Kawamata-machi	10	< 10	Thyroid measurements and whole body counts
Kawauchi-mura	< 10	< 10	Whole body counts
Katsurao-mura	20	< 10	Substitution with data obtained in Namie-machi
Iwaki-shi	30	10	Atmospheric dispersion simulations and thyroid measurements
Minamisoma-shi	20	< 10	Substitution with data obtained in Namie-machi
Other	< 10	< 10	Atmospheric dispersion simulations

*Tokonami et al.[16]　(Unit: mSv)

simulations.

II. Calculation Method

Each internal exposure dose resulting from inhalation is calculated using the equation below by means of an atmospheric concentration map for a target nuclide obtained through an atmospheric dispersion simulation.

$$D_i = e_i \int C_i(x(t),t) \cdot B(t) \cdot F(t)dt$$

In this equation, the index i denotes a nuclide, D_i denotes the internal exposure dose from nuclide i, e_i denotes the dose coefficient for internal exposure from inhalation, $C_i(x(t),t)$ denotes the atmospheric concentration at location $x(t)$ for the target individual at time t, $B(t)$ denotes the respiratory rate, and $F(t)$ denotes the correction factor for factors such as the dose reduction resulting from remaining indoors.

In the previous fiscal year, the NIRS reassessed the early internal exposure doses for residents of Fukushima Prefecture by adopting atmospheric concentration maps for ^{131}I and ^{137}Cs that were calculated using the second worldwide version of SPEEDI (WSPEEDI-II)[7]. These maps were available as two-dimensional time-series data (mapped only with the atmospheric concentration in the bottommost layer including the ground surface) for the period from March 12 to April 30, 2011, based on calculations covering all of eastern Japan (i.e., an area extending 690 km east-west and 960 km north-south). These maps had a horizontal spatial resolution of roughly 3 km each and a temporal resolution of one hour. Examples of WSPEEDI-II being applied to the Fukushima Daiichi Nuclear Accident are presented in some of the reference materials[8-10].

The abovementioned internal exposure dose coefficient and the respiratory rate were assigned with reference to values set in sources such as publications by the International Commission on Radiological Protection (for children aged three months, one year, five years, ten years, and 15 years as well as adults)[11, 12]. Although a reference was available for the dose reduction resulting from remaining indoors[13], this value was not taken into account in the present calculation.

The following section mainly presents the calculated thyroid doses resulting from the inhalation of ^{131}I.

III. Results and Discussion

1. Thyroid Dose Maps

Figure 1 presents thyroid dose maps for children aged one year and adults. These maps were produced by multiplying the mapped atmospheric concentration for ^{131}I with the thyroid equivalent dose coefficient (inhalation) for each of the corresponding age groups and the daily respiratory rate and then performing a time integration. The thyroid doses were assessed for the period from March 12 to March 31, 2011. Even if this period is extended, the thyroid dose increase is little. The thyroid equivalent dose coefficient was a weighted average of 60% of the coefficient for elemental iodine and 40% of the coefficient for particulate iodine (type F).

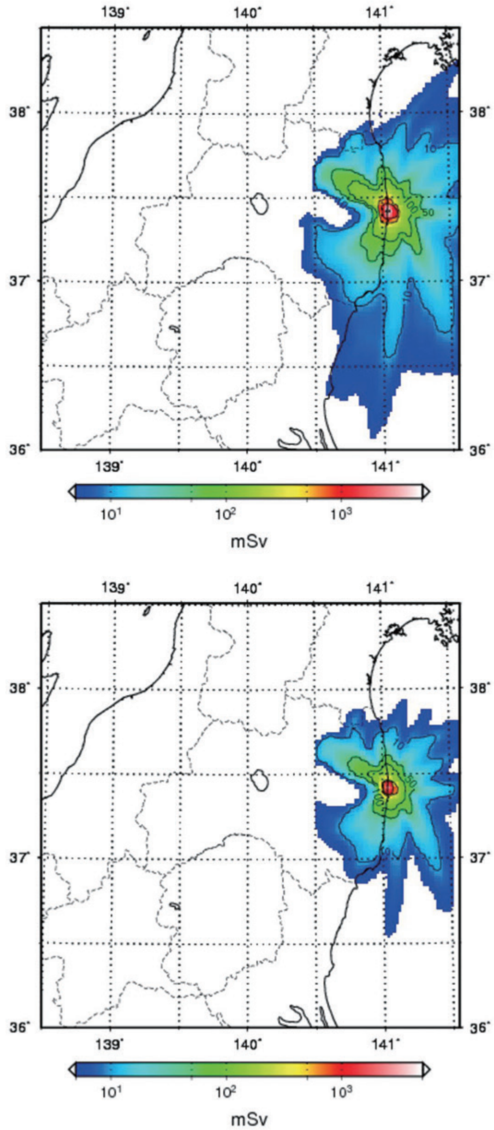

Figure 1 Thyroid dose maps (top: children aged one year; bottom: adults)

The proportion of the physical properties of iodine was assigned with reference to the outcomes from air sampling performed on the premises of the Fukushima Daiichi Nuclear Power Plant, the Fukushima Daini Nuclear Power Plant, and the Japan Atomic Energy Agency in Ibaraki Prefecture.

The maps in Figure 1 show the thyroid doses for persons who remained outdoors at the relevant spots. These doses cannot be applied to residents who evacuated or otherwise moved from one place to another. In fact, most residents living within 20 km of the plant had already evacuated beyond this range by the end of March 12 [14)]. These doses are likely to have been overestimated given factors such as the dose reduction resulting from staying indoors and the thyroid intake rate of iodine in blood among Japanese people [15)]. For this reason, the thyroid dose maps in Figure 1 need to be interpreted with care. Nonetheless, they provide a general overview of the thyroid doses for local residents who did not move many times and residents in neighboring prefectures. In the map for children aged one year, the areas with a thyroid dose that far exceeds 10 mSv extend across the Hamadori region and its surrounding areas in Fukushima Prefecture.

2. Estimation of Thyroid Doses among Evacuees

Thyroid doses resulting from the inhalation of ^{131}I among evacuees from the 20 km range or deliberate evacuation areas were estimated based on the model evacuation behavior cases (**Figures 2** and **3**)[2] that were referenced during estimations of the external exposure doses. These model cases were considered typical behavior patterns based on the actual routes taken by the evacuees. **Table 2** presents the thyroid doses from the respective model cases for children aged one year and 10 years as well as adults. The figures were rounded to one significant digit taking into consideration the required level of accuracy.

The doses in model cases for evacuations from the 20 km range are generally kept lower compared to those for evacuations from deliberate evacuation areas. This difference owes significantly to evacuations to beyond this range that took place before March 15 when a massive release occurred at the Fukushima Daiichi Nuclear Power Plant. Increased doses have been noted among evacuees who fled to the northwest of the plant. In model cases for evacuations from deliberate evacuation areas, almost all of the doses were received at the evacuees' points of origin because of the lateness of the evacuations.

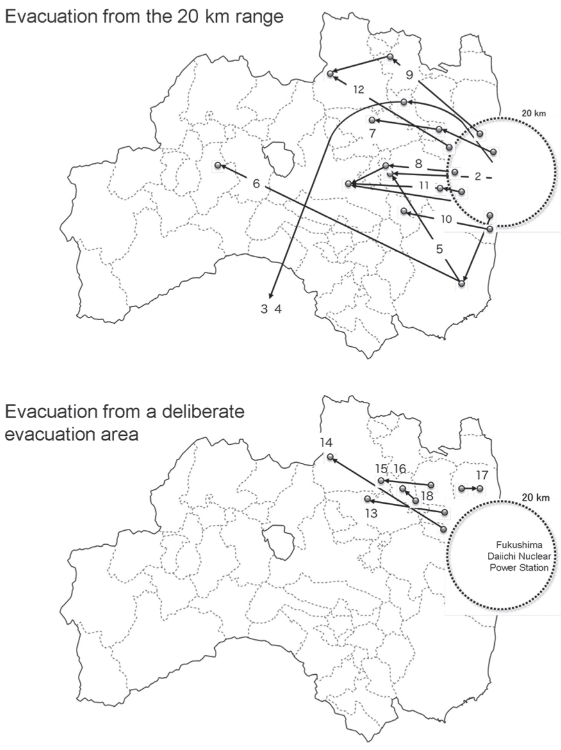

Figure 2 Model evacuation behavior cases (top: evacuation from the 20 km range; bottom: evacuation from deliberate evacuation areas)

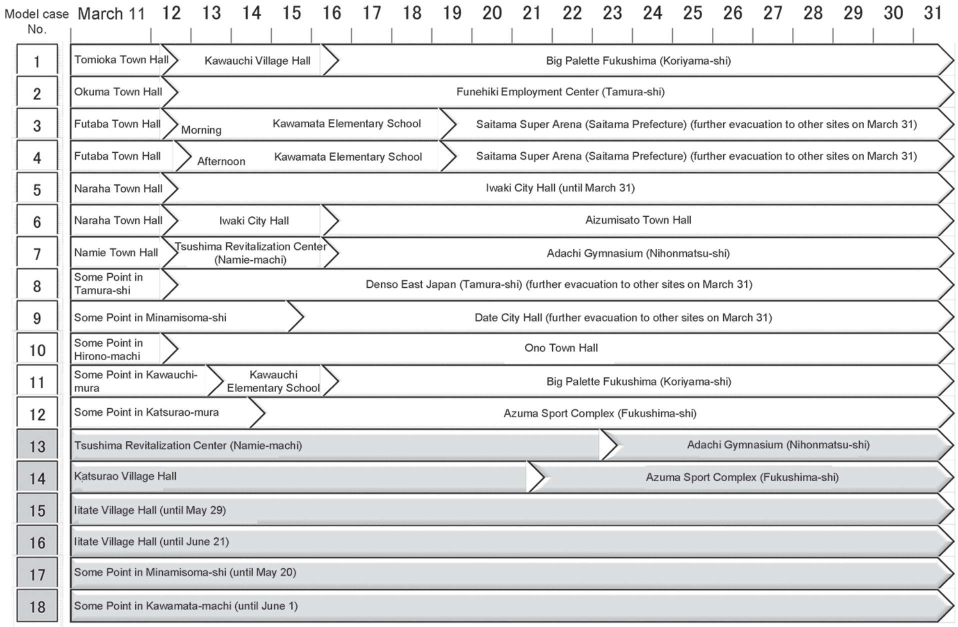

Figure 3 Timeline for model evacuation cases (Cases 1–12: evacuation from the 20-km range; Cases 13–18: evacuation from deliberate evacuation areas)

Table 2 Estimated thyroid doses from the inhalation of ^{131}I according to model evacuation behavior cases by age group

Model case No.	1	2	3	4	5	6	7	8	9
Children aged one year	< 10	< 10	40	90	30	10	90	< 10	< 10
Children aged ten years	< 10	< 10	40	70	30	< 10	80	< 10	< 10
Adults	< 10	< 10	20	40	20	< 10	50	< 10	< 10

Model case No.	10	11	12	13	14	15	16	17	18
Children aged one year	10	< 10	< 10	100	40	30	30	80	70
Children aged ten years	< 10	< 10	< 10	90	30	30	30	70	60
Adults	< 10	< 10	< 10	50	20	20	20	40	30

(Unit: mSv)

3. Comparison with Dose Estimations Based on Data from Actual Measurements Conducted on People

As means of verifying the accuracy of dose estimations produced by atmospheric dispersion simulations, a comparison with thyroid doses estimated based on limited data from actual measurements conducted on people (thyroid measurements and whole body counts) was attempted. The latter estimates, which are based on actual measurements, are probably closer to the true values despite a certain level of uncertainty associated with intake scenarios as conditions for calculating the internal exposure doses (e.g., intake dates and channels).

Figure 4 shows the distribution of thyroid doses estimated based on the results of screening tests conducted in Kawamata-machi, Iwaki-shi, and Iitate-mura in late March 2011 to determine thyroid exposure among children. As an intake scenario, the inhalation of the entire amount of ^{131}I on March 15 was assumed. This figure also shows thyroid doses estimated from the atmospheric dispersion simulations for the purpose of comparison. Because the addresses and behavior of the examined individuals were unknown, the thyroid doses for children aged 5 years were calculated based on the geometric mean (GM) and the geometric standard deviation (σ_g) for the atmospheric concentration of ^{131}I extracted at the closest grid point to each municipal office in the calculation area used for WSPEEDI-II and eight adjacent grid points. As this figure demonstrates, thyroid doses estimated through atmospheric

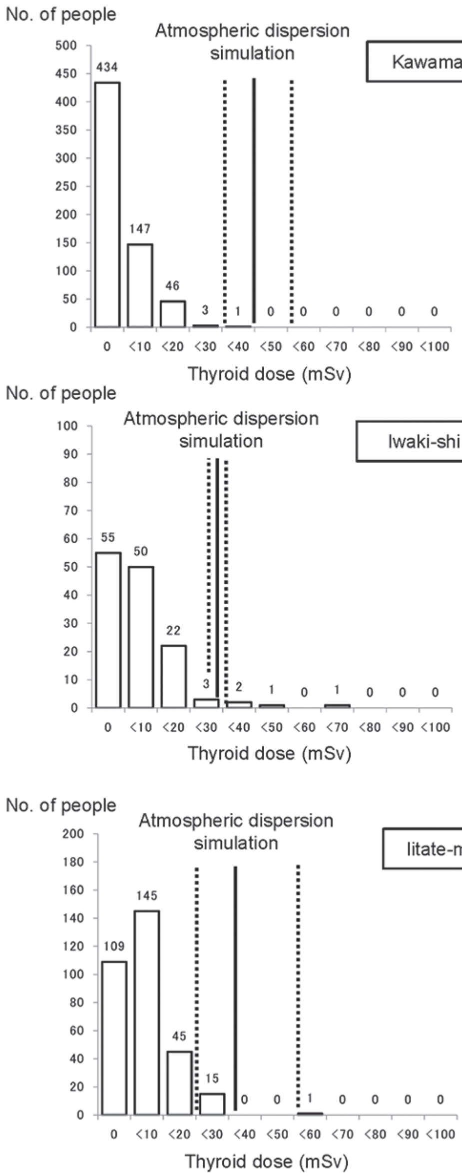

Figure 4 Estimated distribution of thyroid doses based on screening tests for thyroid exposure among children and estimates from atmospheric dispersion simulations
(Solid line represents GM and dashed lines represent GM/σ_g and GM × σ_g'; see main text)

dispersion simulations are close to the upper limits of the thyroid dose distribution obtained from the actual measurement data.

A comparison of estimates made with respect to evacuees is presented below. It should be noted that this comparison is intended for reference purposes only since the behavior of individuals is unclear.

Professor Tokonami of Hirosaki University and his group have reported the results of thyroid measurements that they conducted on residents of Namie-machi [16)]. The measurements were conducted on 62 individuals (45 from the coastal area and 17 from the Tsushima District). The maximum estimated thyroid dose was 33 mSv among adults and 23 mSv among children. These figures are a few dozen percent of the thyroid doses produced by the model cases for evacuations from Namie-machi (Nos. 7 and 13 in Table 2). The estimations produced by atmospheric dispersion simulations tend to result in larger doses. In some cases, however, thyroid dose estimates based on actual measurements (Table 1) conducted on residents of municipalities within 20 km of the plant are higher than those based on the model evacuation behavior cases from these municipalities.

4. Current Status of Reassessments of Early Internal Exposure Doses through Atmospheric Dispersion Simulations

The accuracy of internal exposure doses estimated by atmospheric dispersion simulations has yet to be fully verified. In the last fiscal year, therefore, the early internal exposure doses were reassessed for residents of Fukushima Prefecture by employing atmospheric dispersion simulations only for areas where data from actual measurements conducted on people could not be obtained (Table 1). Atmospheric dispersion simulations played a key role in the two regions of Nakadori and Aizu in Fukushima Prefecture. The estimated thyroid doses in the relevant municipalities are low (less than a few mSv in Fukushima-shi and Koriyama-shi, for instance). Taking into consideration the uncertainty associated with these estimates, it was considered appropriate at present to only indicate that doses are less than the confidence limit (assumed value: 10 mSv). As an exception, the dose estimations produced by atmospheric dispersion simulations were also referenced in the estimates for residents from Iwaki-shi. This was considered necessary backup because thyroid exposure screening tests were conducted on only a small number of children from Iwaki-shi. Estimations were assigned for Katsurao-mura and Minamisoma-shi by applying the available dose estimations based on actual measurements conducted on people in the neighboring municipality of Namie-machi.

IV. Conclusion and Future Prospects

The NIRS investigated the application of atmospheric dispersion simulations in reassessing the early internal exposure doses for residents of Fukushima Prefecture who had been affected by the accident at TEPCO's Fukushima Daiichi Nuclear Power Plant. The thyroid doses estimated through these atmospheric dispersion simulations and those estimated using data from actual measurements conducted on people had almost the same order of magnitude, but there was still a sizeable gap between them. For this reason, internal exposure dose estimations produced by atmospheric dispersion simulations should be regarded only as a point of reference.

Going forward, internal exposure doses may be estimated by effectively applying information on the behavior of individuals in a similar manner to that used in estimating external exposure doses. This method may be validated by estimating the doses through the use of atmospheric dispersion simulations for individuals based on available information concerning their behavior, thyroid measurements, and other data from actual measurements and then comparing them with dose estimations based on data from actual measurements. Doing this allows more realistic individual intake scenarios to be developed with reference to the outcomes of atmospheric dispersion simulations and so forth. The nuclide inhalation quantity is probably influenced considerably by differences in the behavior of individuals during the passage of a radioactive plume (i.e., a stream of air carrying radioactive materials just like smoke), such as whether they were indoors or outdoors and whether they were active or asleep. The author believes that fine-tuning models according to data on the behavior of individuals can significantly enhance the accuracy of internal exposure dose estimations. Given this, it is essential to enhance the accuracy of atmospheric dispersion simulations, and the author expects experts in this field to play an active role in achieving this.

This commentary is partly based on a project commissioned to the NIRS in FY2012 by the Ministry of the Environment to assess the impact of the Fukushima nuclear emergency. The Japan Atomic Energy Agency provided values calculated using WSPEEDI-II to facilitate this commissioned study of the internal exposure doses for iodine and other nuclides with a short half-life in the immediate aftermath of the nuclear accident.

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Roles and Limitations of Atmospheric Dispersion Calculations

−Is It Possible to Make Atmospheric Dispersion Simulations that are Useful and Informative in a Nuclear Accident?−

Nagoya University, **Hiromi Yamazawa**

There has been some confusion with respect to atmospheric dispersion calculations for radioactive materials released from nuclear facilities at the Fukushima Daiichi Nuclear Power Plant during and after the accident. The assessments of atmospheric dispersion in the nuclear field tend to focus excessively on the assessment methodology, such as "to use the dispersion models in this way," while neglecting actually happening phenomena in the natural world. An overall revision is probably required to address what kind of methodology should be adopted for the assessments of atmospheric dispersion in the nuclear field.

I. Introduction

Most of the onshore environmental impact produced by the accident at the Fukushima Daiichi Nuclear Power Plant (such accident being hereinafter referred to as the "Fukushima Accident") was associated with the atmospheric dispersion of radioactive materials. Since the Accident, the calculation of atmospheric dispersion has been discussed in a variety of settings. There has undeniably been some confusion with respect to the adequacy of the results from the estimations made using SPEEDI at that time and the way that they were handled. Similarly, the method used to estimate dispersion in relation to the revision of the Nuclear Emergency Preparedness Guide has proven controversial, as has the interpretation of the results. Meanwhile, the calculation of atmospheric dispersion associated with the Fukushima Accident is applied in post-hoc analysis, such as, inverse estimation of the release rate from monitoring data and analysis of the migration of airborne radioactive materials during the accident.

This commentary first provides an overview of atmospheric dispersion phenomena and then outlines the roles played by, or expected from, the atmospheric dispersion calculations as well as their inherent limitations. The author believes that both the providers of calculation functions, who develop and operate models, and the recipients, who use the resultant information, need to understand these roles and limitations accurately in accordance with their respective levels of responsibilities. This approach offers the most direct way of making the

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most of obtained information while avoiding the unnecessary confusion that can result from an excessive focus on details concerning the phenomena of atmospheric dispersion and their calculations. Although this commentary is not exhaustive, it is expected to serve as an entry point for substantive discussions among persons who make use of the data produced from atmospheric dispersion calculations.

II. Overview of the Realistic Picture of Atmospheric Dispersion Phenomena and Its Calculation

1. What Determines Atmospheric Dispersion?

Any materials released into the atmosphere is subjected to the following: (1) advection in a wind field; (2) dispersion by atmospheric turbulence; (3) removal by deposition or other such phenomena; and (4) disappearance or generation through physical or chemical changes. The concentration in an affected area is determined mostly by these factors. Advection and dispersion are determined by the atmospheric conditions alone, except for in the case of large particles of the target materials that have notable gravitational sedimentation. On a side note, some have explained in reference to the impact of the Fukushima Accident that, without the involvement of rainfall, the (dry) deposition of radioactive materials and the like depends on gravitational sedimentation, but this is misleading. In fact, gravitational sedimentation has only a marginal environmental impact. In dry deposition, the dominant factors are downward turbulent transport in the atmosphere and transport (i.e., the inertial collision and Brownian dispersion of particulate matter and the molecular dispersion of gaseous matter) in the air near the surface of objects on the ground (e.g., soil, vegetation, and buildings).

To return to the topic of discussion, **Figure 1** provides a schematic illustration of the space and time scales involved in atmospheric dispersion and the related meteorological phenomena. The factors that influence advection and dispersion vary depending on the targeted time

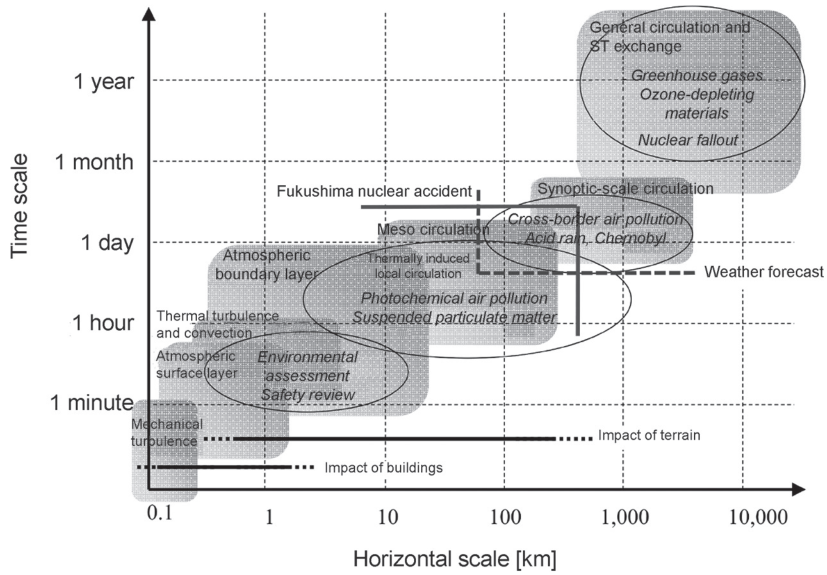

Figure 1 Time and space scales for atmospheric dispersion and influential meteorological phenomena

and space scales. An extensive movement across several hundred kilometers or more is determined by synoptic-scale circulation phenomena, such as lows, highs, and fronts. The relatively limited impact of small geographical features and short-term changes on this scale makes it relatively easy to calculate atmospheric dispersion and assess the extensive distribution of concentration. Examples of this include the Europe-wide impact of the Chernobyl Accident, the transport of materials that cause acid rain, and the extensive transport of suspended particulate matter (SPM).

On a scale of around 100 km or less (i.e., a mesoscale), advection and dispersion are influenced significantly by factors that matter relatively less if a more extensive scale is used. For instance, the airflow, which is mainly determined by the local terrain, shapes the courses of advection and dispersion. The terrain also has an impact through thermal effects (e.g., the mesoscale thermally induced circulation of land and sea breezes as well as mountain-valley winds), which in turn influence the turbulence structure in the atmospheric boundary layer. The thermal impact may change considerably in the course of a few hours. In an even smaller horizontal range of a few kilometers, some terrains can be assumed to be homogenous (flat). An assessment of dispersion can, excluding the impact that buildings have on the dispersion process, be easily performed using adequate on-site wind measurements.

The impact of the Fukushima Accident varies greatly according to the degree of impact in question. Full-scale decontamination is required within the range of a few dozen kilometers. The air dose rate is believed to have substantially exceeded the natural fluctuation within the range of a few hundred kilometers due to the accident. For this type of scale, the general direction of advection is determined by the winds generated from the synoptic-scale circulation associated with lows, highs, fronts, and the like. The meteorological phenomena in this space scale are familiar to us due to their coverage in weather forecasts. The general winds produced in the synoptic scale are observed almost directly as local winds out at sea or on plane fields. However, the spatial distribution of winds is altered considerably by mountains and other topographical features. Even with the same terrain, the degree of change may differ significantly depending on the temperature stratification in the atmosphere. The more stable the stratification is, the more pronounced the air currents are along routes that bypass mountains or pass through valleys and saddlebacks. Such mesoscale local wind fields are formed by the difference in land and sea temperatures and the heating and cooling of mountain slopes during the day and at night. Phenomena of this scale were influential within the range that experienced a significant impact from the accident.

2. How to Calculate?

Any numerical calculation of atmospheric dispersion phenomena first requires the calculation of the wind speed distribution and the turbulence distribution involved in advection and dispersion as well as the calculation of the precipitation distribution (with these three types of distributions being referred to collectively as a “meteorological field”) for the deposition calculation. The calculated meteorological field is applied to calculate the airborne concentration of the target materials and the amount of its deposition on the ground surface (**Figure 2**). Various methods can be applied based on the target space scale and the purpose of the assessment. The most standard method can be described as follows.

The standard method applies the results obtained from an objective analysis or numerical forecast based on data gained from routine observations performed by meteorological organizations (e.g., JMA, ECMWF, and NOAA) in meteorological fields of the global or synoptic scale (i.e., covering a few thousand kilometers). For instance, updated data from the JMA can

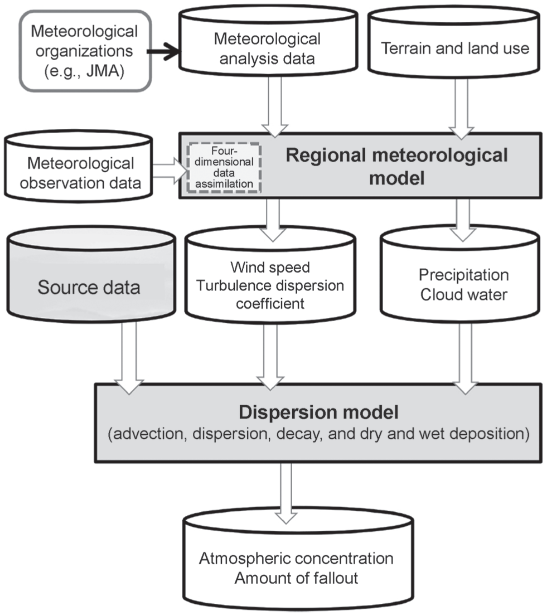

Figure 2 Typical process for the calculation of atmospheric dispersion

be obtained online a few times a day to perform instant calculations as long as a line has been properly installed. The calculated wind corresponds to the general wind mentioned earlier. This wind is applied as the initial and boundary conditions to calculate the meteorological field in detail by using each atmospheric dynamic model (regional meteorological model) for a specific area of interest (e.g., East Japan or in the environs of Fukushima Prefecture). The results are applied to calculate the advection, dispersion, and deposition of the target materials.

In the past few decades, the marked advancement in regional meteorological models has made it possible to calculate meteorological fields that take into account local terrain and thermal impact on land and at sea. Precipitation is highly reproducible given appropriate initial and boundary conditions. In addition, some community models are used by large number of researchers involved in the field of atmospheric science (e.g., MM5, WRF, and RAMS). The forecast performance of these models is verified and improved in various respects. Most models adopt four-dimensional data assimilation to reflect any observation data related to winds and the like in the calculation of atmospheric dynamics, thereby making it possible to enhance the accuracy of the calculation as long as observation data is available. Nonetheless, the assimilation is widely applied only in the calculation of meteorological fields. No standard assimilation methods have been established for calculating dispersion. WSPEEDI-II and most other atmospheric dispersion models for analyzing the impact of the Fukushima Accident adopt the abovementioned standard method. SPEEDI also employs its own regional meteorological model.

These atmospheric dispersion models are being developed and employed even in Japan by numerous research institutes and universities. Private companies (e.g., weather service providers and environmental consultancies) are also capable of performing the necessary calculations. Proper calculations that have been performed using the standard method do not produce any significant differences between the wind fields calculated using different models in a synoptic scale or a larger mesoscale (i.e., meso-α or meso-β scale across 20 km or more).

However, differences may be produced in small-scale wind fields, the vertical structures of turbulence fields, and precipitation patterns due to differences in settings such as the adopted cloud physics processes, the turbulence models, the grid settings, and the boundary conditions of the ground surface and the sea surface. In addition, the methods used to handle wet disposition (e.g., the modeling approach, accuracy, and parameter values) vary significantly in the dispersion calculation, and they are recognized to produce significant differences between models in the calculated distributions of the deposited amount and the atmospheric concentration. Currently, the Science Council of Japan is spearheading an intercomparison of the major models that have been adopted to assess the impact of the Fukushima Accident.

In relation to the standard method mentioned earlier, the calculation of atmospheric dispersion over more extensive areas requires less detailed consideration of the terrain, as is the case in regional meteorological models. These calculations depend largely on data obtained from meteorological organizations. Naturally, the prediction accuracy depends on the data that is obtained from these organizations. Conversely, detailed calculations of meteorological fields and atmospheric dispersion over smaller areas (e.g., a few kilometers) grow increasingly difficult due to the more pronounced influence of smaller terrains and terrestrial objects (e.g., buildings). Nonetheless, provided we assume a flat terrain as well as homogeneous and steady state meteorological field, a simplified calculation (plume model) may be applied for atmospheric dispersion by assuming the Gaussian distribution as the analytical solution of the dispersion equation. One example of this type of model is MACCS2, which is commonly used in Level 3 PSA and has been employed by the Nuclear Regulation Authority in its dispersion assessments. The scope of application for the plume model is limited because the assumption is not realistic in most cases. In each case of dispersion, the concentration must be calculated after confirming that the assumption of a steady state and homogeneous meteorological field has been satisfied.

III. Selection of the Appropriate Method for Each Assessment

The previous section explained the basics and methods for calculating atmospheric dispersion in general terms. The appropriate method must be selected according to the intended purpose and assessment target, while also bearing in mind its limitations. It is particularly important to identify the requirements in light of the purpose of the intended assessment, such as to obtain average and steady state values is enough or not, to obtain dynamic fluctuations in specific cases is needed or not, or to consider the terrain, weather, and other local characteristics is needed or not. Different approaches must be taken in the assessment of dispersion associated with an accident. In doing this, it is important to clarify the relevant goals, such as ex-ante predictions for responding to emergencies or detailed ex-post assessments.

1. Environmental Assessments and Safety Reviews

The plume model is employed extensively in the calculation of atmospheric dispersion for the concentration and dose assessments in environmental assessments and reactor safety reviews. In most of these cases, the plume model is employed to assess the average concentration over a relatively small distance of a few kilometers over a short time period (e.g., one hour). The results obtained from multiple calculations of dispersion are then superimposed to assess the annual average concentration. This practice is reasonable because a flat terrain and a constant meteorological field over a period of one hour can be expected to a certain degree.

However, an hourly calculation of the concentration becomes less rational in the event of changing wind directions and atmospheric stability (hence, turbulence field) or if the impact of the terrain cannot be ignored. Even if the terrain is flat, the assumption of a homogeneous spatial wind field and turbulence field does not reflect reality. Each calculated value should be applied with great care. The plume model is applied to calculate the average figure over a long period not only because of the practicality of the simplified method, but also because random parts of the errors from the assessment of each case of dispersion associated with the simplified model are expected to cancel each other out by the superimposition of the calculation results. This effect has been confirmed in the long-term field dispersion experiment conducted by the author and his colleagues in Tokai-mura.

2. Prediction of the Accident Impact

An assessment of the impact of an accident in almost real time or its predicting for the next few hours or a few dozen hours targets one event at a certain point in time to follow factors such as the space distribution of the atmospheric concentration, the deposition amount (surface concentration), and the dose rate as well as changes in these factors over time. As highlighted by the accident in question, an assessment of the dispersion across 10 km or more is susceptible to the impact caused by unsteady meteorological field and the local terrain. The application of a plume model would appear to be unreasonable because of the oversimplification of its dispersion process.

The application of the simple model may be possible provided the terrain is flat and that there is a small temporal change in the meteorological field (mainly winds) associated with thermally induced circulation and synoptic-scale circulation (Figure 1). The plume model could be reasonably applied to nuclear facilities in the US or European countries, which tend to be located on terrain that is flatter than that in Japan. However, it is unclear whether this type of model can be easily applied to nuclear facilities in Japan, which are mostly located on complex coastal terrains. Few Japanese nuclear facilities are located on flat terrains.

The results for atmospheric dispersion calculations performed based on the standard method are affected by uncertainty concerning the release rate and other source data as well as the calculations per se. The verification of the model has been done using data from dispersion experiments conducted with artificial tracers and data from actual accidents. For instance, the verification of WSPEEDI-II using data from the Chernobyl Accident demonstrated that the calculated deposition amount was within the range of one fifth to five times that of the actual measurements in about 65% of the target spots [1]. In general, the calculated overall distribution patterns of the atmospheric dispersion are highly reproducible. However, the atmospheric concentration and the deposition amount at each spot often differ from the actual measurements by several factors. In other words, even if the direction and manner of advection and dispersion can be roughly reproduced by the calculation, even tiny differences in the plume position and arrival time translate into a large difference in the concentration at the target spot at each point in time because of the significant gradient in the concentration at the edge of the plume. Consequently, in order to predict the impact of an accident, it is better to track the overall distribution pattern and its changes over time, rather than follow the specific values at each target spot.

The source data is essential for predicting the concentration, dose rate, and other absolute values. However, the experience gained from the Fukushima Accident demonstrates that it is difficult to predict the release rate in advance. Nonetheless, provided real-time data is available from stack monitors or surrounding monitoring equipment and allowing for a certain degree of uncertainty, it might be possible to assess the current distributions of the dose rate and concentration based on the proportional relation between the obtained measurements and the calculated values. Nowcasting might also be possible with the concentration and dose rate in the area where the plume is expected to arrive in one or two hours.

3. State of Dispersion Predictions Performed in Response to the Fukushima Accident

A commentary provided in this journal describes the findings from a review of the results obtained from many calculations performed using SPEEDI in the immediate aftermath of the Fukushima Accident [2]. The author reached a similar conclusion after his own analysis based on the general approach to performing dispersion assessments for an accident as discussed in the previous section. Part of his findings will be presented in the report issued by the AESJ Investigation Committee on the Accident at the Fukushima Daiichi Nuclear Power Plant. In summary, the author shared the following findings.

(1) The overall dispersion processes could be reproduced in many cases, although the direction of advection could not be reproduced in some cases.

(2) In many cases, the complex dispersion associated with time varying wind directions could be predicted. Inaccuracies were limited to one or two compass points in the wind directions or two or three hours when the wind directions changed.

(3) The integrated values of the deposition amount and dose rate over a period of 24 hours (regarding the impact of the events that took place mainly in the afternoon on both March 12 and 15) had already been obtained before dawn or in the morning of the same day. The predicted results were closely aligned with the actual state of contamination.

(4) Except for the ex-post calculations announced by the Nuclear Safety Commission on March 23 and other dates, all of the calculations were carried out using a hypothetical release amount or the unit amount. Therefore, the absolute values of the concentration and dose rate had not been obtained by any calculations.

By piecing together these facts, it was possible to produce very reliable predictions using the atmospheric dispersion calculation with uncertainties in the plume arrival time of a few hours and in the plume directions of 45 degrees. However, it was difficult to predict the dispersion with errors of up to one hour and one compass point. About half a day before both March 12 and 15, the impact could already be predicted accurately to be able to say something like, “From late afternoon through to this evening, the impact today is expected to be experienced in the northwest (including west-northwest and north-northwest).” Combined with the real-time dose rate data obtained along the site boundary, these predictions could be very useful information.

Uncertainties concerning predictions generally include those contained in the meteorological data obtained from the meteorological agency. For instance, when a low-pressure system passes through the target area, a prediction may err considerably depending on the pathway and relative position of the plume. Nonetheless, predictions can be extremely useful in predicting one or two days in the future, as long as such limitations are taken into account. In fact, calculations performed using WSPEEDI-II could be used to make some predictions two or three days in advance that are closely aligned with the state of dispersion as we understand it today. Examples include the slight impact observed on land from March 16 to 19 that was mainly due to the plume advancing over the sea, the clockwise landward advancement of the plume on March 20 that affected the area from north Miyagi to south Iwate with the wet deposition of materials released on the same afternoon, and the plume that stalled over the Kanto region (advancing toward Tokyo) from March 21 to 22 to cause deposition by precipitation. Due to space limitations, instead of the relevant figures being included here, these forecast results have been published on the websites of the NRA and other relevant organizations as of the writing of this commentary.

4. Ex-Post Analysis of Accident Impact

In the early phase of the accident, almost no measurements were conducted to determine the atmospheric concentration. Retrospective calculations of the atmospheric concentration must be performed to assess the internal dose from inhalation. To predict one event with a high accuracy, such an ex-post analysis has the same requirements as the aforementioned predicting of the accident impact. The difference lies in the possibility of performing calculations by incorporating the observed meteorological data. As explained earlier, regional meteorological models enable four-dimensional data assimilation. In general, such an assimilation can be performed over the entire timeframe to enhance the accuracy of the calculation.

Unfortunately, many of observational meteorological data are missing from the Fukushima Accident. Especially during the initial phase, measurements could not be performed around the site due to the earthquake and the subsequent tsunami. As such, the assimilation of observation data has not had much effect. Before the calculation results are used, it is important to keep in mind that, to a certain degree, they have similar limitations to those for the aforementioned predicting of the accident impact. The direct application of the calculation results is not necessarily sensible even with high temporal and spatial resolutions for the atmospheric dispersion. These results should be used with the appropriate temporal and spatial resolutions while keeping in mind the possibility of temporal errors in the precipitation and changes in the concentration being caused by changes in the wind direction as well as possible errors in the location of the plume by a few mesh points.

5. Estimation of Source Data

It is extremely difficult to keep track of the species, amount, release locations, and physiochemical conditions of radioactive materials released into the environment both during and after a nuclear accident. In such circumstances, the vital information that is required includes the concentration and dose rate measured in the environment. Many attempts have been made for not only the Fukushima Accident [3)] but also other preceding events [4)] to extract information related to release sources by employing atmospheric dispersion calculations. Details can be found in the reference materials, but the basic approach for this method involves searching for the release rate needed to reproduce the concentration and dose rate measured in the environment by performing atmospheric dispersion calculations.

The author and his colleagues have conducted studies concerning incidents such as the Fukushima Accident, the Chernobyl Accident, the criticality accident at Tokai-mura and the release of Cs-137 from Algeciras. These studies have led them to the following findings. It is difficult to estimate the release rate precisely from environmental data. In most cases, however, rough estimates can be produced that may differ by about three times. The uncertainty of such estimates is mainly due to the uncertainty of the atmospheric dispersion calculation and the inadequacy of the temporal and spatial representativeness of the measurement values. Many kinds of measurements are conducted, including the atmospheric concentration in gaseous and particulate forms, the ground surface concentration (per area and per environmental sample weight), and the dose rate (the contribution of plume and ground surface deposition). Their temporal and spatial densities are inhomogeneous and sparse. For these reasons, it is difficult to develop a tool with a predetermined procedure and method. The release rate must be estimated in an ad-hoc manner. With respect to the method, special attention must be paid in relation to the adoption of Bayesian statistics or other mathematical methods in the development of relevant technologies. They may prove effective in certain circumstances, but the essence of making estimates could be misunderstood if it is simply regarded as a matter of mathematical or numerical solutions.

6. Ex-Ante Atmospheric Dispersion Calculations with Postulated Accidents

In recent years, systematic calculations of the atmospheric dispersion of materials released in postulated accidents have been conducted mainly by local governments to provide a reference for emergency preparedness. This new practice is driven by the perceived needs of local governments to understand the nature, extent, and severity of the impact of postulated accidents according to the respective local characteristics so that they can fulfill their responsibility to protect residents on the ground in the event of an accident. These calculations, exemplified by those conducted by the prefectural governments of Shiga and Gifu, are sensible responses to the Fukushima Accident.

The author led the committee for Gifu Prefecture in conducting a calculation aimed at identifying (1) local or seasonal factors that may influence the nuclear impact in the prefecture; and (2) the geographical extent of the areas that are expected to be affected significantly and the severity of the impact. This calculation also adopted the basic approach explained in sections III-2 to III-4. To achieve the first goal, detailed calculations were performed using atmospheric dispersion over a period of one year by reproducing the local terrain and past weather conditions. Dispersion characteristics associated with the local terrain that was identified in the calculation were used to deploy monitoring posts. The computation requirements are not slight, but they can be achievable relatively easily given the capability of computers today.

Meanwhile, the meteorological guidelines issued by the former Nuclear Safety Commission state that a dose assessment must be performed after any accident by using the plume model and the statistical value (97 percentiles from the least impact). This stipulation has remained unchanged for over 30 years without revision. When the author first came across these guidelines more than twenty-five years ago, he questioned the soundness and validity of this approach. An environmental assessment certainly takes a similar approach in that it takes note of the statistical characteristics of any changes in the concentration of permanently present environmental materials. It is unclear whether this approach can be applied to any release of radioactive materials caused by a specific accident. This question remains unresolved.

IV. Conclusions

This commentary provided an overview of atmospheric dispersion and the various assessment methods. It went on to explain the current practices employed in nuclear-related assessments and their possible future. The quantitative understanding of atmospheric dispersion remains insufficient, particularly with respect to wet deposition. However, models that are available to us today still hold useful potential. Unfortunately, this fact remained unrecognized among nuclear societies before and after the Fukushima Accident. Arguably, a "dinosaur-like" method that is mixed up with principles and was defined more than a quarter of a century ago is still blindly followed, even though it is probably irrelevant to the actual phenomena to be assessed. The author believes that an overhaul is much needed to address how atmospheric dispersion is calculated in the nuclear field in order to understand and assess the phenomena that are actually encountered based on scientific principles and practices.

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Commentary

Progress on Off-Site Cleanup Efforts in Fukushima

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Seiji Ozawa

In 2011, the accident that occurred at the Fukushima Daiichi Nuclear Power Plant, which is operated by the Tokyo Electric Power Company (TEPCO), led to the release of radioactive materials and extensive environmental pollution in Fukushima Prefecture and its surrounding areas. The Japanese government and other stakeholders have been conducting cleanup efforts pursuant to the Act on Special Measures Concerning the Handling of Environmental Pollution by Radioactive Materials Discharged by the Nuclear Power Plant Accident Associated with the Tohoku District – Off the Pacific Ocean Earthquake That Occurred on 11 March 2011 enacted in August of that year. To date, extensive decontamination work has been completed in four of eleven municipalities in Fukushima Prefecture through operations carried out directly by the Japanese government. Coordination is also underway to prepare interim facilities for the storage of the soil removed during the decontamination work. This commentary provides an overview of the cleanup efforts conducted so far and reports on the challenges ahead.

KEYWORDS: Off-site cleanup, decontamination, radioactive pollution, Fukushima

I. Implementation System for the Cleanup Efforts Led by the Japanese Government

In 1999, the Act on Special Measures Concerning Nuclear Emergency Preparedness was enacted to implement special measures pursuant to the Basic Act on Disaster Control Management. The enactment of the Act on Special Measures Concerning the Handling of Environmental Pollution by Radioactive Materials Discharged by the Nuclear Power Plant Accident Associated with the Tohoku District – Off the Pacific Ocean Earthquake That Occurred on 11 March 2011 (hereinafter referred to as the "Special Measures Act") was necessary because the cleanup of pollution caused by radioactive materials as stipulated in Article 26 of the Act on Special Measures Concerning Nuclear Emergency Preparedness was not applicable beyond the site of a nuclear utility. This section provides an overview of this Special

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Measures Act, its basic principles, and the Fukushima Office for Environmental Restoration, which was established for the performance of cleanup efforts.

1. Implementation System for Cleanup Efforts

(1) Special Measures Act

In 2011, the accident that occurred at the Fukushima Daiichi Nuclear Power Plant, which is operated by the Tokyo Electric Power Company (TEPCO), led to the release of radioactive materials and extensive environmental pollution in Fukushima Prefecture and its surrounding areas. In response, lawmakers passed legislation in the form of the Special Measures Act in August 2011. Having been passed and enacted, the Special Measures Act was fully enforced in January 2012.

Pursuant to the Special Measures Act, Special Decontamination Areas were designated for the cleanup efforts that were carried out directly by the Japanese government, while Intensive Contamination Survey Areas were designated for the cleanup efforts led by municipal governments. In addition, areas for the contaminated waste treatment in Countermeasure Areas were assigned for designated types of waste that had a contamination level in excess of a certain threshold.

(2) Basic principles of the Special Measures Act

The basic principles of the Special Measures Act were approved by the Cabinet in November 2011. Cleanup and other efforts made pursuant to the Act are intended to ensure the swift mitigation of the impact on human health and living environments. These principles also established the following targets in the basic approach to cleanup efforts.

- Swiftly reduce the size of areas that have an additional annual exposure dose of 20 mSv or more in a phased manner.
- Pursue a long-term target of securing an additional annual exposure dose of no more than 1 mSv in areas that currently have an additional annual exposure dose of less than 20 mSv.

According to these principles, Special Decontamination Areas for the cleanup efforts carried out by the Japanese government are designated keeping in mind areas with restricted access. Decontamination and other measures were to be pursued until the end of March 2014. As an exception, the Japanese government was to conduct a pilot project to establish a suitable decontamination method before applying it in their cleanup efforts in areas with particularly high additional exposure doses.

Meanwhile, Intensive Contamination Survey Areas, where the additional exposure dose was 1 mSv or more, were designated for the cleanup efforts led by municipal governments.

The Japanese government was assigned the responsibility to install and ensure the safety of the Interim Storage Facilities needed for the treatment of the removed soil and so forth.

2. Establishment of the Fukushima Office for Environmental Restoration

Following the enactment of the Special Measures Act in August 2011, the Japanese Ministry of the Environment (MOE) deployed a team to facilitate cleanup efforts based in Fukushima City. This team is in charge of communicating and coordinating with the prefectural government and relevant municipalities of Fukushima. In January 2012, the Fukushima Office for Environmental Restoration was established in Fukushima City to conduct decontamination work and other measures with the aim of keeping pace with the full enforcement of the Act. The office was positioned under the Tohoku Regional Environment Office (Headquarters in Sendai) as a regional branch of the MOE.

The office initially consisted of 40 members, but this number was increased to about 200 in April 2012 when five branches were opened throughout the prefecture (north: Fukushima; central and south: Koriyama; Aizu: Aizu-Wakamatsu; northern Hamadoori: Minamisoma; southern Hamadoori: Hirono). From that April, municipal governments with designated Special Decontamination Areas began planning their cleanup efforts, seeking consensus from residents on the planned decontamination, and discussing the acquisition of land for use as Temporary Storage Sites for the removed soil and so forth. In April 2013, the number of staff had been increased to 300 to engage in the full decontamination and waste treatment and develop Interim Storage Facilities. In April 2014, the office was expanded to 390 members, with about one-third of these members coming from the respective ministries. Some of them were land improvement specialists from the Ministry of Agriculture, Forestry and Fisheries, while some others were field engineers for roads and rivers from local offices of the Ministry of Land, Infrastructure, Transport and Tourism. The remaining two-thirds were publicly recruited from among citizens from different parts of Japan, although about half of them were from Fukushima Prefecture. In April 2015, the office is expected to expand to have about 500 members.

II. Progress on Off-Site Cleanup Efforts

1. Special Decontamination Areas

Special Decontamination Areas were assigned for the decontamination work carried out directly by the Japanese government in eleven municipalities, mostly from the Hamadoori region in Fukushima Prefecture. By summer in 2013, plans had been developed for the cleanup efforts carried out by the Japanese government in ten of these municipalities, excluding Futaba. The plans all aimed to complete the decontamination work by the end of March 2014. In September 2013, the progress made in relation to decontamination was reviewed in all of the municipalities in Special Decontamination Areas. As a result, the plans for some municipalities were revised in December 2013 to move away from the prior target of completing the decontamination and transportation of contaminated soil to Temporary Storage Sites across the board within two years (FY2012–2013).

Decontamination was completed in Tamura (Miyakoji District) by June 2013. The original plan for the completion of the decontamination work was maintained in Kawauchi, Naraha, and Okuma. The planned completion was postponed to the end of FY2015 in two municipalities (Kawamata and Katsurao) and to the end of FY2016 in four municipalities (Minamisoma, Iitate, Namie, and Tomioka). A plan for decontamination work in Futaba was developed in July 2014 with the intention of completing the work by the end of FY2015.

Table 1 presents the progress that had been made in carrying out decontamination work in eleven municipalities in Special Decontamination Areas as of November 2014. Further cleanup efforts will be conducted in larger municipalities that have relatively higher doses.

Follow-up monitoring will be conducted with municipalities that have completed the decontamination work to verify that the effects of their efforts are maintained. Other follow-up tasks will be considered as necessary in coordination with the local community members.

Table 1 Progress made in cleanup efforts conducted in Special Decontamination Areas [1)]

Municipality	Approx. population in decontamination target area (persons)	Approx. area of decontamination target (ha)	Revision of target area	Decontamination progress (as of Nov. 30, 2014, in municipalities with unfinished cleanup efforts)				Schedule [a)]		Lifting of Evacuation Order
				Decontamination plan	Temporary Storage Sites, etc.	Consent from local communities	Decontamination work	Completion in residential areas	Completion in other areas	
Tamura	400	50	Apr. 2012	Apr. 2012	Secured	Gained	Completed Jun. 2013	FY2013 (already completed)		Apr. 2014
Kawauchi	400	500	Apr. 2012	Apr. 2012	Secured	Gained	Completed Mar. 2014	FY2013 (already completed)		Oct. 2014 in zones preparing to lift evacuation order
Naraha	7,700	2,100	Aug. 2012	Apr. 2012	Secured	Gained	Completed Mar. 2014	FY2013 (already completed)		To be determined
Okuma	400	400	Dec. 2012	Dec. 2012	Secured	Gained	Completed Mar. 2014	FY2013 (already completed)		To be determined
Katsurao	1,400	1,700	Mar. 2013	Sept. 2012	Secured	Almost gained	Underway	Summer 2014 (already completed)	Within 2015	To be determined
Kawamata	1,200	1,600	Aug. 2012	Aug. 2012	Approx. 90%	Almost gained	Underway	Summer 2014 (already completed)	Within 2015	To be determined
Minamisoma	13,300	6,100	Apr. 2012	Apr. 2012	Approx. 80%	Approx. 50%	Underway	FY2015	FY2016	To be determined
Iitate	6,000	5,600	Jul. 2012	May 2012	Secured	Approx. 90%	Underway	Within 2014	Within 2016	To be determined
Namie	18,800	3,300	Apr. 2013	Nov. 2012	Approx. 30%	Approx. 50%	Underway	FY2015	FY2016	To be determined
Tomioka	11,300	2,800	Mar. 2013	Jun. 2013	Approx. 90%	Approx. 90%	Underway	FY2015	FY2016	To be determined
Futaba	300	200	May 2013	Jul. 2014	Under coordination	In preparation	Preparations underway	FY2015		To be determined

2. Pilot Decontamination Demonstration Project in Difficult-to-Return Zones

In Special Decontamination Areas, decontamination work was to be conducted in Habitation Restricted Areas and Preparation Areas for Lifting of Evacuation Order. In Difficult-to-Return Zones with an annual total dose rate of 50 mSv or more, a pilot demonstration project was to be carried out to investigate what approach should be adopted to deal with the contamination. In FY2013, a pilot decontamination demonstration project was carried out in six districts in Namie and Futaba. In every target district, the air dose rates at a height of 1 m above the ground surface in habitation zones (residential areas, farmland, and roads) were reduced by around 50 to 70%. These areas had initially had high dose rates. Even after this reduction, the average dose rates per hour at a height of 1 m exceeded 8 μSv in some residential areas.

3. Intensive Contamination Survey Areas

Pursuant to the Special Measures Act, areas with an additional annual exposure rate of 1 mSv or more other than Special Decontamination Areas were designated as Intensive Contamination Survey Areas. In these areas, cleanup efforts are led by municipal governments.

As of January 2015, 36 of the 39 designated municipalities in Fukushima Prefecture have developed plans for their cleanup efforts. The three remaining municipalities of Yanaizu, Yamatsuri, and Hanawa have no prospects of planning any decontamination work. Leaving aside these three municipalities, decontamination work has been conducted for about 60% of residential areas, 40% of roads, and 80% of schools and other public facilities.

[a)] Planned completion of decontamination work (residential and other areas).

4. Waste Treatment in Countermeasure Areas for the Direct Treatment of Contaminated Waste

Countermeasure Areas where contaminated waste was to be treated directly by the Japanese government were designated in eleven municipalities with an overlapping designation as Special Decontamination Areas. The total amount of disaster waste from these areas is estimated to be around 802,000 tons. By January 2015, 25 Temporary Storage Sites had been put into service as a provision measure for meeting the storage needs.

In seven municipalities (other than Okuma, Futaba, Kawamata, and Tamura), plans were formulated for the construction of temporary incinerators to treat the combustible part of the disaster waste from these areas. By March 2015, their construction had been begun at seven places in six municipalities: Tomioka, Minamisoma, Namie, Katsurao, Kawauchi, and Iitate (Warabidaira District and Komiya District). Four of these incinerators were put into service in Kawauchi, Iitate (Komiya District), Tomioka, and Minamisoma.

5. Treatment of Designated Waste

Beyond the designated areas, waste with a radioactivity level in excess of 8,000 Bq/kg is treated by the Japanese government as designated waste. In Fukushima Prefecture, the estimated amount of designated waste amounted to roughly 130,000 tons. Efforts to reduce the volume of combustible waste have been pursued by incineration and drying. With facilities for reducing the volume of sewage sludge having been constructed in the cities of Fukushima and Koryiama so far (completed in FY2014), the treatment such sludge is now underway. In addition, a facility in Samegawa is being used to treat agricultural and forestry waste. Plans have also been formulated for the treatment of combustible designated waste at the volume reduction incinerator that is under construction in the Warabidaira District, Iitate.

6. Fukushima Eco-Tech Clean Center

Plans are in place for the landfill disposal of designated waste with a radioactivity level of no more than 100,000 Bq/kg at the existing controlled disposal site (Fukushima Eco-tech Clean Center). The intended targets are waste in the designated areas, designated waste, and household garbage from the Futaba District with a radioactivity level of 100,000 Bq/kg or less. The estimated amount of waste to be disposed of is about 650,000 m^3. The disposal plan is being coordinated with the target municipalities.

7. Interim Storage Facilities

The construction of Interim Storage Facilities with a combined area of roughly 16 km^2 is planned in Okuma and Futaba. These facilities will store soil removed during decontamination work in Fukushima Prefecture, waste in the designated areas and designated waste with a radioactivity level of over 100,000 Bq/kg. The total amount of waste to be stored is estimated to be between 16 and 22 million m^3 (after the incineration of combustible waste). The main steps that have been taken for the completion of this construction work are as follows.

2012 Mar.: The Japanese government requests that the prefectural government and eight municipalities in the Futaba District investigate the feasibility of the construction work.
Nov.: The prefectural government agrees to conduct a field survey.

2013 Apr.: The field survey (boring survey, etc.) is begun.
Jun.: The Japanese government begins investigating safety measures at the facilities.
Dec.: The Japanese government requests that the prefectural government and relevant municipalities host the facilities.
2014 May: The Japanese government begins organizing briefings for members of the community in Okuma and Futaba.
Sept.: The prefectural government agrees to conduct the construction work and confirms five key conditions.
Sept.: The two host towns agree to begin giving due explanations to landowners.
Nov.: The JESCO Act [b)], which stipulates the final disposal of waste outside of Fukushima Prefecture, is enacted.
Nov.: A basic plan is developed for the transportation of waste to the Interim Storage Facilities.
Dec.: Okuma agrees to the construction.
2015 Jan.: Futaba agrees to the construction.
Jan.: A plan for the transportation of waste to the Interim Storage Facilities is formulated.
Feb.: The construction of the Interim Storage Facilities is begun.
Feb.: The Japanese government explains to the prefectural government how the five key conditions are being addressed.
Feb.: The prefectural government and the two towns agree to accept the transported waste.
Mar.: Transportation of the waste to the Interim Storage Facilities is begun.

In February 2015, the Interim Storage Facilities were constructed in parts of some industrial complexes in Okuma and Futaba. The trial transportation of soil removed from municipalities in the prefecture is planned for 2015.

The planned sites for the Interim Storage Facilities are owned by over 2,300 landowners. These landowners should obviously be duly briefed and efforts must be made before the development of these facilities to gain their understanding with respect to the planned usage of their land. In tandem with the decontamination and waste treatment work, continued efforts must be made to provide the necessary explanations to the relevant municipalities and evacuees to gain their understanding of the intended cleanup project.

III. Risk Communication Involved in Decontamination Work and Other Measures

The cleanup efforts can be carried out provided there is sufficient understanding and support from the affected residents, local municipalities, and relevant organizations. For this reason, the relevant municipalities and the prefectural government communicated the associated risks to local residents from right after the disaster. In January 2012, at almost the same time as the Special Measures Act came into full enforcement, the Decontamination Information Plaza was opened in Fukushima City to serve as a center for communicating the risks involved in decontamination work and other measures. Sometime later in May 2014, Support

[b)] JESCO Act stands for the revised Act on Japan Environmental Storage & Safety Corporation.

Center for Social Workers Engaged in Recovery from the Nuclear Disaster (hereinafter referred to as the "Support Center for Social Workers") was established in Iwaki City to support consultants appointed to work closely with evacuees who decide to return to their homes while communicating the associated radiation risks.

1. Decontamination Information Plaza

The Decontamination Information Plaza was opened in January 2012 to serve as an information hub on decontamination work and radiation. Run jointly by the MOE and the prefectural government of Fukushima, the plaza dispatches registered decontamination and radiation experts to conduct risk communication work as requested by the municipalities. The Atomic Energy Society of Japan and other related groups provided the necessary support for the opening and operation of the plaza as well as the dispatching of experts [2)]. The plaza exhibits information and models that facilitate a greater understanding of decontamination work and radiation. Upon request by a municipality, the content of these exhibitions is brought to an event held by the municipality to organize a mobile exhibition.

From February 2012 to January 2015, the plaza dispatched about 700 experts to workshops that were organized by the municipalities and attended by over 25,000 participants. Mobile exhibitions were held at 320 locations for a total of about 440 days, hosting almost 40,000 participants. The plaza hosted over 17,000 visitors.

2. Support Center for Social Workers

To provide close support for returnees and address their concerns about radiation, a system for the deployment of consultants was established in line with NRA recommendations issued on November 20, 2013 ("Basic Approach to Ensuring Safety and Providing Reassurance for Returnees with Specific Protective Measures According to the Dose Level") and Cabinet approval issued on December 20, 2013 ("Accelerating the Restoration of Fukushima in the Wake of the Nuclear Accident"). The Support Center for Social Workers was established by the MOE in Iwaki City to provide scientific and technical support to consultants through training and other such measures.

IV. Future Challenges

As of February 2015, about 6 million m^3 of removed soil contained in bags (about 1 m^3 each) and the like are being managed temporarily at approximately 1,000 Temporary Storage Sites and directly in over 80,000 storage sites. This soil will be transported to keep pace with the development of the Interim Storage Facilities. In anticipation of further cleanup efforts and the time that will be required for their completion, affected residents who wish for the restoration of their daily lifestyles and a return to their homes should be kept informed. This communication remains vital in addition to the steady implementation of decontamination work and other measures.

V. Conclusions

Ever since the nuclear accident took place in 2011, the Japanese and municipal governments have been conducting cleanup efforts while seeking the understanding and support of affected residents. This commentary presents a summary of their efforts by focusing on Fukushima Prefecture. These cleanup efforts are a necessary step toward the restoration of Fukushima Prefecture. Unfortunately, some people from Difficult-to-Return Zones and other affected areas are still stranded in evacuation shelters. The nuclear accident has shattered the trust that citizens had in the Japanese government and power utilities, which used to have a strong influence on the daily lives of people in their communities. People have suffered great pain and been left dazed with grief over the loss of their livelihoods and a homeland filled with memories. Their despair defies our imagination. Even so, we must steadily carry out our efforts to restore their communities given their strong feelings of attachment.

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Commentary

Behavior of Radioactive Cesium through Paddy Field Works
-Report from Field Tests in Minamisoma City-

Tohoku University and member of the Cleanup Subcommittee for the Fukushima Special Project, **Nobuaki Sato**

Since 2011, the Cleanup Subcommittee has been conducting puddling tests and paddy rice cultivation tests in Minamisoma City. The overall concept of the field tests was explained first. After that, the radioactivity measurement results for the presence of cesium and potassium in soil, rice plants, and brown rice were examined to understand the migration behavior of radioactive cesium, and the effectiveness of potassium fertilization and zeolite addition in reducing the concentration of cesium was then assessed.

KEYWORDS: Paddy field test, radioactive cesium, decontamination, potassium fertilization, zeolite addition, brown rice, plowing, threshing, polishing

I. Introduction

In the Fukushima Special Project that is being implemented by the Atomic Energy Society of Japan, the Cleanup Subcommittee has been working to pursue environmental remediation and local reconstruction in response to the disaster that occurred at the Fukushima Daiichi Nuclear Power Plant. This work includes radiation monitoring, recommendations related to environmental remediation, the sharing of information on decontamination technologies and temporary storage yards, the performance of field tests to demonstrate paddy restoration technologies, and the holding of talks with local communities [1-3]. Importantly, the committee has been conducting field tests on the decontamination of rice paddies in Minamisoma City, a practice that is little known outside Japan, in order to examine the behavior of radioactive cesium in rice paddies and assess decontamination techniques [4]. **Table 1** presents the decontamination techniques that are applied in paddy rice cultivation. The field tests were deemed necessary for plowing, puddling, and fertilization taking into consideration their levels of difficulty, the strain exerted on farmers, and the expected effects. Puddling tests and other paddy rice cultivation tests were conducted in partnership with the Japan Agricultural Cooperatives (JA) for Soma and Minamisoma City from 2011 to 2014 to study the migration behavior of cesium in rice plants and brown rice as well as the decontamination effect of potassium fertilization. This paper presents the findings from the field tests.

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Table 1 Decontamination techniques in paddy rice cultivation

No.	Method	Description	Remarks
(1)	Plowing	Mechanical or manual plowing to reduce cesium concentration in topsoil	Inexpensive No contaminated materials produced
(2)	Topsoil scraping	Removal of deposited cesium by scraping off topsoil	Depth Secondary contaminated materials
(3)	Puddling	Forced drainage of turbid water during puddling to remove particles contaminated with cesium	Treatment of wastewater, etc.
(4)	Soil washing	Stripping cesium from soil minerals and soil organic matter by using a cleaning solution	Field work Soil recovery
(5)	Phytoremediation	Cultivation of plants that easily absorb cesium and removal after the harvest	Less effective Treatment of secondary contaminated plants
(6)	Fertilization	Fertilization with K (discourage) and NH_3 (encourage) to regulate migration of cesium to crops	Inexpensive

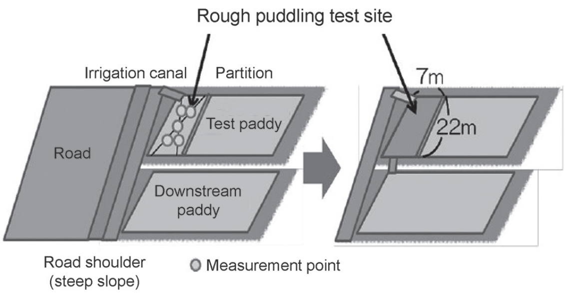

Figure 1 Rough puddling test site

II. Overview of Field Tests

1. Puddling Tests

In 2011, puddling tests were conducted in a rice paddy (10 m × 50 m) located in the Hirohata district of Baba, Minamisoma City, Fukushima Prefecture (**Figure 1**). This district is between 20 and 30 km from the Fukushima Daiichi Nuclear Power Plant. The test paddy draws in water from a nearby reservoir through an irrigation canal and discharges it into a drainage canal. The paddy was dry, and the grass there was knee-high. The tests were conducted three times: once in August, once in September, and once in November. In August, the test paddy was mowed to measure the air dose rate and take soil samples before and after the plowing. The air dose rate was also measured before and after the puddling to examine how much the exposure dose can be reduced during farm work and to perform a rough check of the decontamination rate for the soil. The plowing was followed by flooding, puddling (rough puddling), drainage, and soil sampling. In September, the second rough puddling test was conducted to sample the soil and drainage water. In November, samples were taken from farm water and the like. These samples were sent to laboratories operated by Tohoku University and Toshiba to measure the radioactivity of ^{137}Cs and ^{134}Cs using their germanium semiconductor detectors. The obtained concentration of radioactive materials was examined to assess the effectiveness of plowing in reducing radioactivity and the effectiveness of puddling in decontamination. The tests provided information on secondary contaminated materials, such as contaminated suspended water containing soil, the grain size distribution and major minerals present in the soil, the analysis of the major minerals, and the sedimentation rate of suspension.

2. Paddy Rice Cultivation Tests

From FY2012 onwards, paddy rice cultivation tests were conducted at a test paddy (20 m × 50 m) in the Hirohata district of Baba, Minamisoma City, Fukushima Prefecture. **Figure 2** presents the steps involved in paddy rice cultivation.

Every year from May to October, tasks beginning from planting, fertilization, harvesting, threshing, and polishing were carried out. At each step, the air dose rate was measured and samples were taken of the soil, rice plants, and water. Zeolite was blended into the soil during the plowing and then sprinkled after the puddling. **Figure 3** presents the farming conditions maintained in the test paddy. The test paddy draws in water from a nearby reservoir through an irrigation canal and discharges it into a drainage canal. The paddy was divided into two sections, one with potassium fertilization and the other without. These sections were then further divided into another three sections depending on the amount of zeolite that was sprinkled, which was none, normal, or double, thereby giving a total of six sections (A–F). Samples of the soil, rice plants, and so forth were taken from each section during the fertilization and zeolite sprinkling. The harvested rice was threshed and then divided into brown rice and broken rice. The former was then further divided into polished rice and bran. These samples were sent to laboratories operated by Tohoku University and Toshiba to measure the gamma

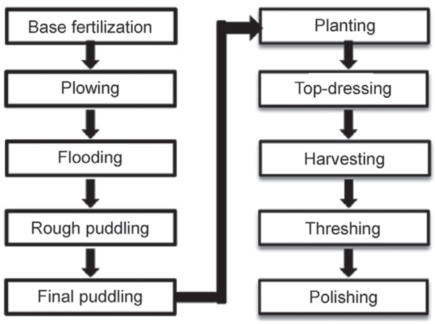

Figure 2 Steps for the paddy rice cultivation test

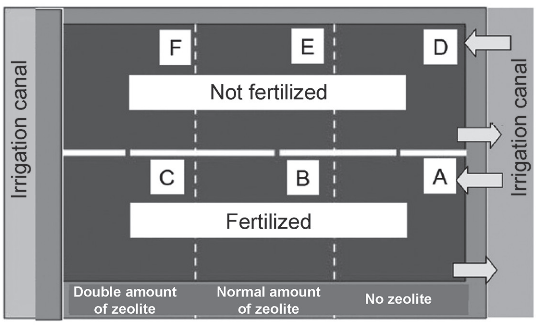

Figure 3 Sections of the paddy used for the rice cultivation test in FY2012

rays emitted from ^{137}Cs and ^{134}Cs with their germanium semiconductor detectors. The obtained radioactivity concentration per dry weight was examined to assess the effectiveness of zeolite addition and potassium fertilization in reducing radioactivity and the effectiveness of puddling in decontamination. The tests provided information on the migration behavior of radioactive cesium and decontamination. Given that top-dressing had no visible impact in FY2012, the emphasis was placed on base fertilizers over the following two years. Further tests were conducted in four sections using different amounts of zeolite, as shown in **Figure 4**.

In addition, following the considerable boar damage that resulted in trampled or eaten rice plants in FY2012, the test paddy was protected by electrical wires in subsequent years, as shown in **Figure 5**. Thereafter, rice could be harvested without any damage. Unfortunately, though, boars invaded the plastic greenhouse used for drying harvested rice in FY2014, leaving behind only a few dozen samples of threshed rice grains.

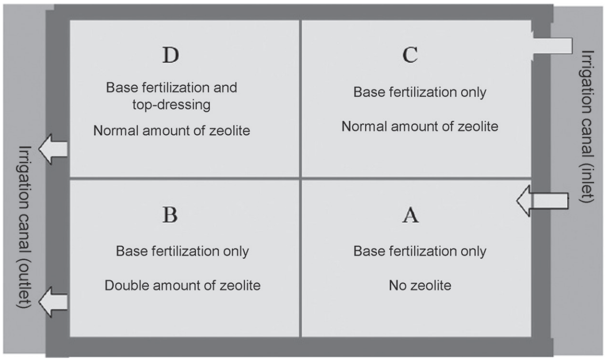

Figure 4 Sections of the paddy used for the rice cultivation tests in FY2013 and FY2014

Figure 5 Protection measures against boars installed in FY2015 and FY2016

III. Test Results

1. Behavior of Radioactive Cesium during Puddling Tests

Puddling tests were conducted in the test paddy by performing the following steps: plowing, rough puddling, and final puddling. After the plowing, a simplified ridgeway was

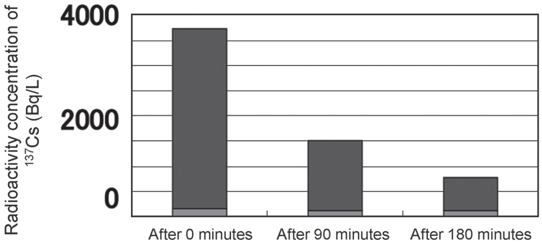

Figure 6 Changes in the radioactivity concentration of ^{137}Cs in drain water over time after the puddling

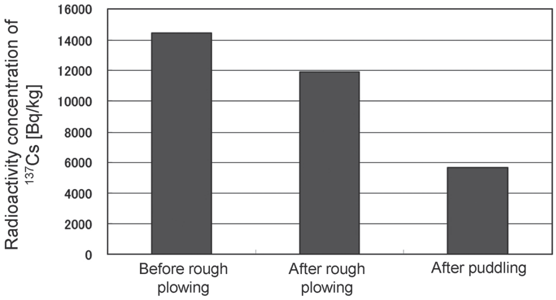

Figure 7 Changes in the radioactivity concentration of ^{137}Cs in the soil before rough plowing, after rough plowing, and after puddling

constructed. Once the paddy had been flooded, rough puddling and final puddling were carried out. Turbid water from the puddling tests was measured after it had been left to stand, with the results demonstrating that the water did not contain cesium. Cesium was contained mostly in the soil particles separated from the water, which indicates that cesium is adsorbed by the clay particles in the soil. These clay particles were suspended by puddling before an attempt was made to remove them from the test paddy by discharging turbid water. **Figure 6** presents the concentration of ^{137}Cs in the discharged water over time after the puddling operation had been performed. The concentration was 3,500 Bq/L immediately before the discharge (i.e., just after the puddling), but this figure dropped to 1,500 Bq/L after 90 minutes and then 750 Bq/L (i.e., less than a quarter) after 180 minutes. Puddling and drainage proved an effective means of performing radioactive cesium decontamination for rice paddies.

Next, changes in the ^{137}Cs concentration in the soil were tracked during the rough plowing, flooding, and puddling steps. The results are shown in **Figure 7**. Rough plowing reduced the concentration of ^{137}Cs in the soil by around 15% from 14,000 Bq/kg to 12,000 Bq/kg, which indicates that the ^{137}Cs adsorbed in the topsoil was diluted through being mixed with the soil underneath. The deeper the plowing was, the greater the reduction in radioactive cesium was. The puddling reduced the concentration even further to below 6,000 Bq/kg. In total, about 60% of the radioactive cesium was eliminated. In conclusion, rough plowing, puddling, and other ordinary techniques that are applied in paddy rice cultivation proved an effective means of reducing the amount of radioactive cesium retained in the soil.

2. Behavior of Cesium during Paddy Rice Cultivation Tests

Paddy rice cultivation tests were first performed at a test paddy in 2012. The average radioactive cesium concentration in the test paddy was 5,400 Bq/kg, which was almost half the level recorded in the puddling test paddy the previous year (over 10,000 Bq/kg). The most likely causes are the decay of ^{134}Cs and the migration of radioactive cesium due to weathering and other weather phenomena. The radioactivity concentration of the cesium and potassium in the soil was measured using samples taken from Sections A to D from the test paddy in FY2013. Similarly, soil samples were taken from two sections of the test paddy in FY2014. The average cesium concentration in the soil was around 3,000 Bq/kg in FY2013 and around 2,500 Bq/kg in FY2014. This concentration had stood at 14,000 and 5,400 Bq/kg in FY2011 and FY2012, respectively. This suggests that the radioactive cesium concentration drops significantly until the third year, after which the reduction slows due to the smaller contribution of ^{134}Cs with a half-life of two years.

In FY2012, the paddy was divided into six segments so that tests could be conducted with and without fertilization and using different amounts of zeolite addition. After the drying and threshing had been performed, the rice plants were divided into straw and roots. Rice husks were collected during the threshing. The measured levels of radioactive cesium radioactivity (^{134}Cs and ^{137}Cs) are presented in **Table 2**. The rice husks and straw contained 100 to 200 Bq/kg of radioactive cesium. Roots washed in water contained about ten times that amount, at between 2,000 and 3,000 Bq/kg. Since the radioactive cesium concentration in the soil of the test paddy was roughly 5,000 Bq/kg, the migration rate to the roots was 60% while that to the straw was up to 2%. In addition, the radioactivity concentration in Sections A, B, and C was slightly lower than that in Sections D, E, and F. Fertilization is believed to have suppressed the cesium absorption by reducing the proportion of cesium in relation to potassium. In a similar manner to that described in another report[5)], a significant reduction was observed for base fertilization, but the impact was reduced in the top-dressing. Moreover, farmers shared a valuable insight when they informed us that excessive potassium addition compromises the taste of the rice. Meanwhile, there were no notable differences associated with the different amounts of zeolite addition used in Sections A, B, and C.

Next, **Figure 8** compares the radioactivity measurement results for radioactive cesium and potassium in the brown rice from each section after threshing in FY2012. This figure demonstrates a low level of radioactivity for cesium of around 15 to 30 Bq/kg compared to about 75 Bq/kg for ^{40}K. The radioactive cesium concentration in Sections A, B, and C, which were fertilized, seems to be slightly lower than that in Sections D, E, and F, which were not fertilized. The proportion of broken rice in the former group was 4.9% compared to 6.3% in the latter group. This difference points to better rice growth owing to fertilization, as well as a

Table 2 Radioactive cesium concentration in rice husks, straw, and roots (Bq/kg)

Section	Fertilization	Zeolite	Rice husks	Rice straw	Roots
A	Fertilized	None	137	189	2844
B	Fertilized	Normal	117	141	2667
C	Fertilized	Double	105	156	1836
D	Not fertilized	None	185	187	2090
E	Not fertilized	Normal	115	180	2013
F	Not fertilized	Double	153	152	1878

reduced specific radioactivity per unit of weight in a heavier rice grain. The reduced absorption of radioactive cesium owing to fertilization should also be taken into account. As a result, the specific radioactivity per kilogram of broken rice was higher than that of brown rice.

Figure 9 presents the concentration of radioactive cesium and potassium in polished rice obtained from the harvested brown rice. In every section, the amount of radioactive cesium was less than 10 Bq/kg. Given that potassium and other nutrients are concentrated in bran (i.e., the outer layers of brown rice), the reduction in the radioactivity concentration of potassium due to the polishing process exceeded that for cesium.

Table 3 shows the concentration of radioactive cesium in the brown rice, broken rice, polished rice, and bran obtained in each section used in the paddy rice cultivation test conducted in FY2013. Broken rice tends to contain more radioactive cesium than brown rice does. The radioactivity is more concentrated in bran than it is in polished rice, which implies that cesium is concentrated in the outer layers of brown rice. The same tendency was confirmed for potassium. No significant differences were noted in a comparison of the figures corresponding to Sections A through D, which indicates that the amount of added zeolite and

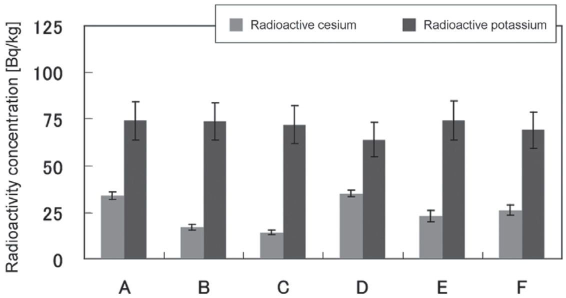

Figure 8 Concentration of radioactive cesium and potassium in brown rice from Sections A to F

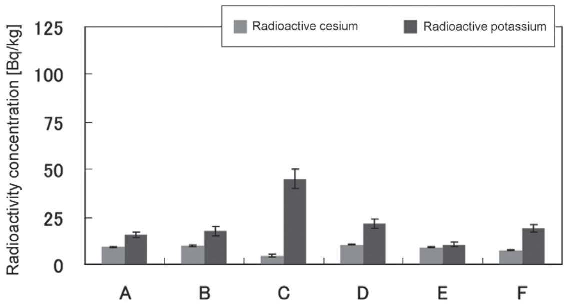

Figure 9 Concentration of radioactive cesium and potassium in polished rice from Sections A to F

Table 3 Radioactive cesium concentration in brown rice, polished rice, etc. (Bq/kg)

Section	Fertilization	Zeolite	Brown rice	Broken rice	Polished rice	Bran
A	Base	None	41	68	27	256
B	Base	Double	27	16	7	174
C	Base	Normal	47	59	13	209
D	Base + top-dressing	Normal	38	99	12	209

top-dressing had a marginal impact. The migration of radioactive cesium from the soil to brown rice was no more than 1%, but greater migration around 4 to 10% was noted for radioactive potassium. Similar results were obtained in the paddy rice cultivation test conducted in FY2014.

IV. Conclusions

This paper reports the results for paddy rice cultivation tests conducted over the course of four years by the Cleanup Subcommittee in Minamisoma City, Fukushima Prefecture. The radioactive cesium concentration in the soil was more than halved over these four years. Base fertilization using potassium proved effective, but not with top-dressing. Zeolite addition had no visible impact. The subcommittee found that only about 1% of cesium migrated from the soil to brown rice, while much more radioactive potassium did. Paddy rice cultivation tests will be continued in the field so that any changes in the migration behavior of radioactive cesium over time can be reported.

We would like to extend our gratitude to JA Soma and farmers for their kind understanding and cooperation in the conducting of these tests.

Members of the Cleanup Subcommittee who participated in the field tests (without honorifics)

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Resuspension and Lateral Transport of Seafloor Sediment Contaminated with Artificial Radionuclides Derived from the Fukushima Daiichi Nuclear Power Plant Accident

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Japan Atomic Energy Agency (present: The University of Tokyo), **Shigeyoshi Otosaka**

In July 2011, settling particle collectors (sediment traps) were deployed on the continental slope located to the southeast of the Fukushima Daiichi Nuclear Power Plant (FDNPP) to assess quantitatively how the particulate radiocesium released in the FDNPP Accident was transported in the ocean. For the subsequent three years, measurements were conducted on the collected particulate radiocesium. Radiocesium from the accident was still detected in the early summer of 2014, and an increasing trend was observed every autumn. The collected particles mostly consisted of lithogenic materials. The collected radiocesium flux was much larger than the radiocesium suspected based on the concentration of dissolved radiocesium in the upper water column. These findings suggested the resuspension of seafloor sediment contaminated with radiocesium and its lateral transport to the continental slope. The observed increase in both the concentration and flux of radiocesium every autumn was presumed to be a result of the increased resuspension and lateral transport of coastal seafloor sediment caused by approaching and passing typhoons.

KEYWORDS: Fukushima Daiichi Nuclear Power Plant, radiocesium, particulate radiocesium, sediment trap, settling particle, seafloor sediment, resuspension, lateral transport, typhoon

I. Introduction

On March 11, 2011, the 2011 Tohoku-oki earthquake, which had a magnitude of 9.0, triggered a major tsunami off the Pacific coast of Tohoku. The ensuing devastation led to the shutdown of cooling systems at the Fukushima Daiichi Nuclear Power Plant (FDNPP), which is operated by the Tokyo Electric Power Company (TEPCO). A large amount of artificial radionuclides was released during subsequent incidents, including the venting, hydrogen explosion, leakage of externally supplied cooling water, and intentional discharge. The FDNPP

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Accident was assigned the maximum level of 7 on the International Nuclear Event Scale (INES), which is the same level as that assigned to the Chernobyl NPP Accident that occurred on April 26, 1986. Radiocesium (i.e., cesium-137 (^{137}Cs)) accounted for the main portion of the released artificial radionuclides. According to the latest estimates [1], 3 to 6 PBq of the total 15 to 20 PBq (10^{15} Bq) of released radiocesium was deposited on land, 3.6 ± 0.7 PBq was directly discharged into the ocean, and the other 12 to 15 PBq was transported to the ocean through the atmosphere. Almost 80% of the released radiocesium ended up in the ocean.

A survey was begun in the immediate aftermath of the accident to monitor the migration, dispersion, and distribution of the radiocesium released into the ocean. Measurements of radiocesium have been conducted on seawater, marine organisms from lower to higher trophic levels, suspended/settling particles, and seafloor sediment. The dissolved radiocesium that was released directly into the ocean migrated and dispersed eastward along the Kuroshio extension. Part of this radiocesium reportedly reached the West Coast of the United States in 2014 [2], while another part gradually infiltrated the ocean interior through convective overturning during winter and the formation of an intermediate water [3].

Part of the radiocesium released into the ocean was captured by marine organisms, suspended/settling particles, and seafloor sediment. The behavior of the radiocesium collected by settling particles has been studied using time-series sediment traps [4].

A sediment trap is a type of settling particle collector that is moored undersea in a fixed position using mooring ropes, a float, an anchor, and a releaser, the latter of which connects the mooring system to the anchor during the sampling period and then releases the anchor when the mooring system is recovered. A time-series sediment trap automatically replaces multiple sampling cups at preset intervals of between a few days and about a month. Time-series sediment traps had been moored at two pelagic zones located in the western North Pacific when the FDNPP Accident took place. They were located at a horizontal distance of about 2,000 km and 1,000 km from the FDNPP (see Observation Sites K2 and S1 in **Figure 1**). These traps were recovered later and the radiocesium in the collected time-series settling particles was measured. The measurements revealed that radiocesium derived from

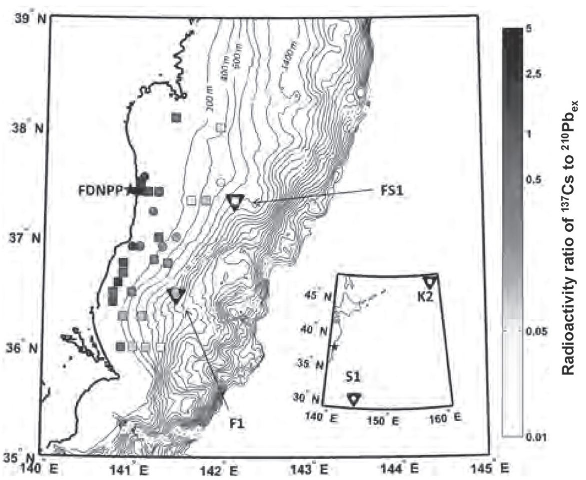

Figure 1 Mooring locations of time-series sediment traps in the western Northern Pacific (open inverted triangles). Depth contours are every 200 m. The background value presents the ratio of radioactivity for radiocesium (^{137}Cs) to the excess radiolead ($^{210}Pb_{ex}$) on the top layer of the seafloor sediment (modified version of Figure 1 from Reference Document #6).

the FDNPP Accident had already been carried vertically to a depth of about 5,000 m at both sites about one month after the accident[5)]. After the accident, time-series sediment traps were also deployed in semi-pelagic zones (Observation Site F1) to observe the particulate radiocesium. This commentary provides a detailed explanation of the results of the survey conducted by the authors and their colleagues (Reference Document #6) at Observation Site F1, which is located 115 km to the southeast of the FDNPP. The measurement of radiocesium in settling particles implies the resuspension of seafloor sediment contaminated with radiocesium from the accident and its subsequent lateral underwater transport toward the continental slope.

II. Observation Research of Settling Particles by Using the Sediment Traps at F1

1. Observation Site and Results from Time-Series Sediment Traps

The observations were conducted using time-series sediment traps over the continental slope (depth: 1,300 m) at Observation Site F1 (36°28’ N, 141°28’ E). Settling particles were collected over a three-year period from July 2011 (i.e., about four months after the FDNPP Accident) until June 2014 at depths of 500 m and 1,000 m. The traps were deployed and recovered roughly once a year and the time-series settling particles were collected at intervals of between 16 and 36 days. The collected particles were taken back to an onshore laboratory to measure the radiocesium (^{134}Cs and ^{137}Cs) by gamma-ray spectrometry with a germanium semiconductor detector. In almost all of the periods, ^{134}Cs was detected in the collected settling particles. Before the accident, ^{134}Cs was almost absent in the environment. Furthermore, the radioactivity ratio of ^{134}Cs to ^{137}Cs (^{134}Cs/^{137}Cs) was almost 1 after radioactive decay correction to March 11, 2011. The ^{134}Cs/^{137}Cs that was released due to the accident was reportedly 1. Given these facts, it is clear that the radiocesium detected in the settling particles originated from the FDNPP Accident.

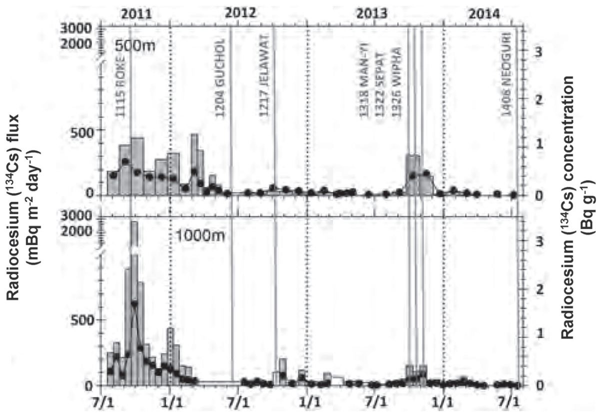

Figure 2 Radiocesium (^{134}Cs) flux (bar chart) and concentration (black circles) at 500 m (top) and 1,000 m (bottom).
White bars represent values interpolated from the preceding and following flux levels. Vertical solid lines represent typhoons that passed within 100 km of the FDNPP during the observation period (modified version of Figure 2 from Reference Document #6).

During Mooring Period I (July 2011 to July 2012), an increase in the ^{134}Cs flux (total radioactivity of particulate ^{134}Cs per square meter per day: mBq m^{-2} day^{-1}) was noted at 500 m during the following periods: September to October 2011, December 2011 to January 2012, and February to March 2012 (**Figure 2**). The same seasonal change was observed at 1,000 m, except that the annual total of the ^{134}Cs flux was about 1.5 times greater than that of the level observed at 500 m. The highest ^{134}Cs flux to date (ca. 2,800 mBq m^{-2} day^{-1}) was observed at a depth of 1,000 m between September and October 2011 [4]. During Mooring Period II (July 2012 to July 2013), the total ^{134}Cs flux was roughly one fifth to one sixth that of Period I. A somewhat high level of ^{134}Cs flux was noted in around October at 1,000 m. During Mooring Period III (July 2013 to July 2014), a high flux that was comparable to that of Period I was observed between September and October 2013 at 500 m. An increase in both the ^{134}Cs flux and the concentration was noted during the same period at 1,000 m. The fact that ^{134}Cs was detected in all of the samples from the site indicated that the transport of the particulate radiocesium produced in the FDNPP Accident continued at the site even after three years.

2. Estimated Origin of Particulate Radiocesium

At 500 m (1,000 m), the annual total ^{134}Cs flux (≈ ^{137}Cs) during Periods I, II, and III amounted to 98 (143), 11 (30), and 46 (33) Bq m^{-2} yr^{-1}, respectively. In his earlier paper [7], one of the authors (Otosaka) proposed using the following equation to estimate the particulate ^{134}Cs flux.

$$FCs = Cw \times K^* \times Fv$$

where Cw denotes the ^{134}Cs concentration (Bq L^{-1}) of seawater at the surface of the observation point (depth: 0 m to 50 m), K* denotes the ratio of the ^{134}Cs concentration in suspended particles to the ^{134}Cs concentration in ambient water (known as the “partition coefficient”; the value in this case being 3.5 L g^{-1}), and Fv denotes the total particle mass flux (mg m^{-2} day^{-1}). Using this equation, the annual total ^{134}Cs flux was estimated to be roughly 3.3 Bq m^{-2} yr^{-1} at Observation Site F1 by applying the overall average total mass flux at 1,000 m during the observation period (740 mg m^{-2} day^{-1}) as well as the ^{134}Cs concentration in the surface seawater near F1 (average concentration at a depth of between 0 and 100 m in May 2012 and May 2013: ca. 3.5 × 10^{-3} Bq L^{-1}) [6]. The estimated value is lower by an order of magnitude than the annual total ^{134}Cs flux observed during the three years at 500 m and 1,000 m (11–98 Bq m^{-2} yr^{-1}). This finding demonstrates that the radiocesium adsorbed on the settling particles that sank from the surface above Observation Site F1 alone cannot account for the particulate radiocesium collected by the sediment traps.

The total mass flux during Mooring Period I (July 2011 to July 2012) was around 770 mg m^{-2} day^{-1} at 500 m and around 980 mg m^{-2} day^{-1} at 1,000 m (**Figure 3**). These total mass fluxes were much higher than the total mass flux observed at around 5,000 m at Observation Sites K2 and S1, which are located in pelagic zones (K2: ca. 160 mg m^{-2} day^{-1}; S1: ca. 45 mg m^{-2} day^{-1}). In sharp contrast to the settling particles at K2 and S1, which mainly consisted of biogenic materials (biogenic opal at K2 and calcium carbonate at S1), more than half of the settling particles at F1 consisted of lithogenic materials. The seasonal change in the particles observed at F1 differed significantly from the typical seasonal change caused by lower trophic biological (zoo/phyto plankton) activity, which is high in spring and summer but low in winter. These conditions suggested that particles rich in lithogenic materials were transported laterally before they were collected by the time-series sediment traps.

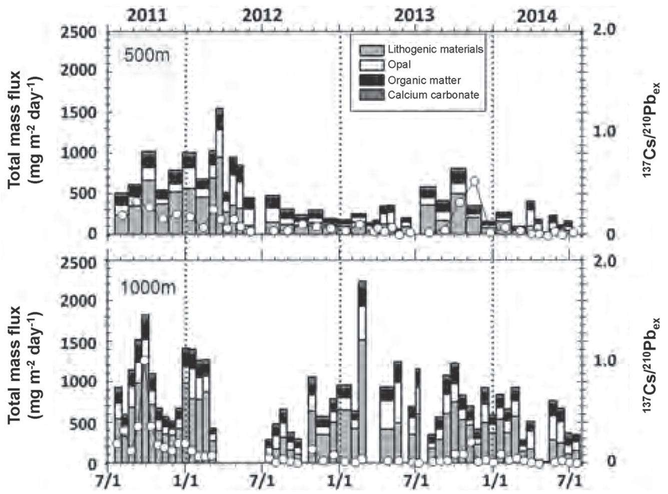

Figure 3 Flux of main components (bar chart) and radioactivity ratio of radiocesium (^{137}Cs) to excess radiolead ($^{210}Pb_{ex}$) ($^{137}Cs/^{210}Pb_{ex}$: white circles) at 500 m (top) and 1,000 m (bottom) (modified version of Figure 2 from Reference Document #6).

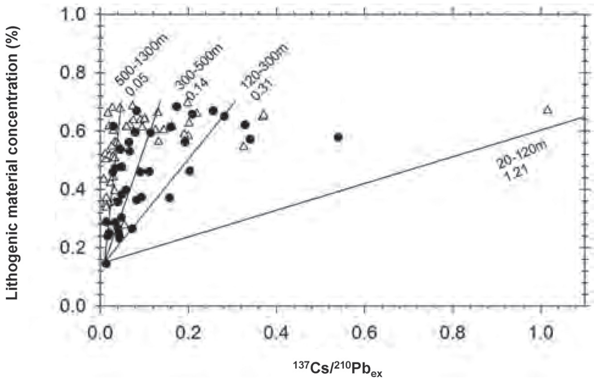

Figure 4 Relationship between $^{137}Cs/^{210}Pb_{ex}$ and the concentration of lithogenic materials for settling particles (black circles and white triangles correspond to traps at 500 m and 1,000 m, respectively). Straight lines in the figure indicate the relationship between $^{137}Cs/^{210}Pb_{ex}$ and the lithogenic material concentration in the seafloor sediment in the environs of the FDNPP at each depth (modified version of Figure S2 from Reference Document #6).

In the next step, the radioactivity ratio of ^{137}Cs to $^{210}Pb_{ex}$ ($^{137}Cs/^{210}Pb_{ex}$) was calculated (Figure 3). Unlike authigenic radiolead, $^{210}Pb_{ex}$ is radiolead that is not generated from the radioactive decay of ^{226}Ra in settling particles (excess radiolead ($^{210}Pb_{ex}$): the total amount of ^{210}Pb that is supposedly supplied from the atmosphere to the surface area above F1 and the ^{210}Pb that is presumably generated in the water column from the surface area above F1 down to the target distance (500 m or 1,000 m in this study) and becomes adsorbed on the settling particles). The calculated $^{137}Cs/^{210}Pb_{ex}$ ranged from 0.02 to 1.0, which are similar to the figures observed for the seafloor sediment in the waters extending from the shallow waters in the environs of the FDNPP to a depth of about 1,300 m near F1 (Figure 1). This finding supports the explanation that radiologically contaminated seafloor sediment was resuspended, laterally transported and then collected by the sediment traps at 500 m and 1,000 m at F1.

Subsequently, the origin of the captured seafloor sediment was estimated by comparing the relationship between $^{137}Cs/^{210}Pb_{ex}$ and the lithogenic material concentration of the settling particles with the relationship for the seafloor sediment in the environs of the FDNPP at the respective depth levels (**Figure 4**). This comparison suggested that a large part of the collected particles might be resuspended seafloor sediment at a depth of over 120 m. The $^{137}Cs/^{210}Pb_{ex}$ in excess of 0.3 is most likely the result of a resuspension of the seafloor sediment in shallower waters (120 m beneath the surface). The settling particles collected each autumn presented a high $^{137}Cs/^{210}Pb_{ex}$ and a high concentration of lithogenic materials (Figure 3). During this season, typhoons passed within 100 km of the FDNPP. Notably, the amount of ^{137}Cs, the $^{137}Cs/^{210}Pb_{ex}$, and the lithogenic material concentrations were high in autumn 2013 when three typhoons passed through the area (Figure 2). These findings indicated the tendency for the heavy weather caused by typhoons to result in the resuspension of the seafloor sediment from shallower waters and the lateral transport to the continental slope where F1 is located.

Resuspension and lateral transport toward the continental slope have also been reported for seafloor sediment located about 100 km to the east of the FDNPP (Observation Site FS1 in Figure 1) based on an observation conducted using a sediment trap at a depth of 875 m[7)]. The total mass flux at FS1 was about half and the radiocesium flux was about 10% compared to the levels registered at F1[6)]. Presumably, the lateral transport of the seafloor sediment from off the coast of the FDNPP was predominantly toward the southeast considering the average direction of the flow of seawater[1)] and the distribution of the radiocesium concentration in the seafloor sediment[8)].

3. Residence Time or Attenuation Time of Radiocesium in Seafloor Sediment in the Environs of the FDNPP

Most of the radiocesium released into the ocean from the FDNPP was suspected to have been dissolved in seawater and then undergone further dilution and extensive dispersion[1, 3)]. On the other hand, the radiocesium that has been deposited in the seafloor off the coast of the FDNPP (down to the depth of 200 m) was estimated to account for several percent of the radiocesium released into the ocean or accumulated onshore (ca. 100×10^{12} Bq or 100 TBq[8)]). However, it is of great concern that, along the coast, the seafloor sediment contaminated with the radiocesium poses a risk to organisms that dwell in these waters. In October and November 2015, over 99.9% of fishery products were reported to have a radiocesium concentration below the safety threshold of 100 Bq kg^{-1} (Fisheries Agency website: http://www.jfa.maff.go.jp/j/housyanou/kekka.html). Based on an observation and simulation, however, it has been reported that benthic organisms experience a slower reduction in the concentration of radiocesium compared to that in ambient water, and the behavior of radiocesium throughout the food chain is still a matter of argument[9)]. Therefore, quantitative studies are crucial to determining how radioactive cesium is removed from the seafloor sediment.

In this study, the annual total ^{134}Cs flux (= ^{137}Cs flux) at 1,000 m over a three-year period was about 70 Bq m^{-2} yr^{-1} [(143 + 30 + 33) ⁄ 3] on average. If we suppose that this figure is the average ^{137}Cs flux in semi-pelagic waters (depth: 200 to 1,500 m) off the coast of Fukushima, Miyagi, and Ibaraki (38.5 to 35.7° N), the annual total amount of radiocesium flux is 1.4×10^{12} Bq yr^{-1} (70 Bq m^{-2} $yr^{-1} \times 2.05 \times 10^{10}$ m^2) or 1.4 TBq yr^{-1}. Moreover, if we assume that this amount of ^{137}Cs is a result of the lateral transport of seafloor sediment from coastal areas shallower than 200 m, the residence time or attenuation time for ^{137}Cs on the seafloor along the coast can be estimated to be roughly 70 years (100 TBq/1.4 TBq yr^{-1}). In other words, most of the radioactive cesium deposited on the seafloor along the coast remains there, while about 1 to 2% migrates offshore every year.

As this study demonstrates, time-series sediment traps are an effective tool for the precise detection of the offshore time-series migration of radionuclides over a long period. Meanwhile, the monitoring data obtained from coastal areas demonstrates that the radiocesium concentration in the coastal sediment is decreasing by a few dozen percent every year (Nuclear Regulation Authority: "Results from marine monitoring" (http://radioactivity.nsr.go.jp)), which is in contrast to our estimate of a few percent every year. This faster decrease can be attributed to the compound effect of the lateral transport of the radiocesium to offshore areas as well as the following processes: 1) the radioactive decay of the radiocesium; 2) the dissolution of the radiocesium in seawater [10]; and 3) the dilution of the radiocesium from disturbances by benthic organisms (bioturbation) [8]. The most crucial task for further marine surveys is to accurately evaluate the balance of these actions and thereby produce forecasts for the marine environment around Fukushima.

Acknowledgments

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Commentary

Prediction of Ambient Dose Equivalent Rates for 30 Years after the Fukushima Accident and its Technological Development

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The Japan Atomic Energy Agency (JAEA) has been developing a model designed to predict the distribution of ambient dose equivalent rates within 80 km of the Fukushima Daiichi Nuclear Power Plant (hereinafter referred to as the "Fukushima Daiichi NPP"). A vast amount of measurement data on ambient dose equivalent rates was used to predict changes in the distribution of such rates over a period of 30 years following the Fukushima Daiichi Nuclear Accident by deriving model parameters according to the respective local characteristics inside and outside the evacuation zones. Both uncertainty analysis and validation of this model were conducted. This commentary characterizes the prediction model for the distribution of ambient dose equivalent rates and its parameters. It also presents ambient dose equivalent rate forecast maps that have been generated using this model.

KEYWORDS: Ambient dose equivalent rate, prediction model, ecological half-life, cesium, vehicle-borne survey, land use, map, Fukushima

I. Introduction

The Fukushima Daiichi Nuclear Accident has compelled us to establish a method for conducting long-term impact assessments to predict the distribution of radioactive cesium deposited in the environment and associated changes in ambient dose equivalent rates. This method is necessary for the provision of basic information that allows residents to keep track of radiation levels, for the selection of appropriate protective measures (including decontamination), and for the reassignment of evacuation zones. Although the deposited radioactive cesium should be identified as a source of radiation for the protection of the public, it is difficult to choose appropriate protective measures due to a lack of sufficient information concerning current and predicted Cs depositions. The experience gained prior to the Fukushima Daiichi Nuclear Accident proved that temporal changes in the radioactive cesium deposited on the ground surface depends on not only radioactive decay, but also weathering effect i.e., impact from changes in the natural environment, such as wind and rain. Making highly reliable predictions is difficult because the radiation levels thus vary in accordance with the natural circumstances of each location and time.

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The JAEA has been developing a distribution prediction model for ambient dose equivalent rates under a project commissioned initially by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) in FY2012 and subsequently by the Nuclear Regulation Authority (NRA) from FY2013 onwards [1-3]. In this model, measurement data on ambient dose equivalent rates within 80 km of the Fukushima Daiichi NPP and data related to land use classification are used for solving an initial value problem. The solutions change from the initial conditions over time until a final solution is produced to predict future distributions. In other words, the model relies on a statistical induction method derived from generalized empirical rules to describe phenomena based on a vast amount of data obtained from extensive investigation of changes in ambient dose equivalent rates according to land use classification. This commentary characterizes the model developed so far for predicting the distribution of and changes in ambient dose equivalent rates. It also presents forecast maps of ambient dose equivalent rates within 80 km of the Fukushima Daiichi NPP that have been generated using this model to aid the further restoration efforts to be made in Fukushima.

II. Distribution Prediction Model for Ambient Dose Equivalent Rates

This model was developed based on a vast amount of measurement data on ambient dose equivalent rates obtained from sources such as a vehicle-borne survey conducted after the Fukushima Daiichi Nuclear Accident. It is aimed at aiding the forecasting of ambient dose equivalent rates from the radioactive cesium deposited extensively within 80 km of the Fukushima Daiichi NPP. This two-compartment model applies ecological half-lives as parameters derived for the various types of land use within 80 km of the plant. Here, an ecological half-life is the time required for the ambient dose equivalent rate in the environment to halve due to weathering, human activity, and various other factors other than the decay of radioactive cesium.

1. Model Equation

The two-compartment distribution prediction model for which radioactive cesium (^{134}Cs and ^{137}Cs) is the source of the ambient dose equivalent rates is expressed in Equation (1) below.

$$D(t)=(D_0-D_{BG})\left\{f_{fast}\exp\left(\frac{-\ln 2}{T_{fast}}\cdot t\right)+(1-f_{fast})\exp\left(\frac{-\ln 2}{T_{slow}}\cdot t\right)\right\}\cdot\frac{k\exp(-\lambda_{134}t)+\exp(-\lambda_{137}t)}{k+1}+D_{BG} \quad (1)$$

In this equation, $D(t)$ is the ambient dose equivalent rate at the elapsed time of t, D_{BG} is the average background ambient dose equivalent rate of 0.05 μSv/h, T_{slow} is the ecological half-life of 92 years for the slow-decaying component, k is the initial ratio of 2.7 for the ambient dose equivalent rate of ^{134}Cs to that of ^{137}Cs (with the same concentration), λ_{134} is the decay constant for ^{134}Cs, and λ_{137} is the decay constant for ^{137}Cs. In Equation (1), the initial ambient dose equivalent rate D_0 is assigned after data from the vehicle-borne survey and other measurements has been converted into an ambient dose equivalent rate within the habitation zones. The values for both T_{fast}, which is the ecological half-life of the fast-decaying component, and f_{fast}, which is a proportion of the fast-decaying component, are derived and assigned based on measurement data obtained from the vehicle-borne survey according to the classification of land use (the cumulative frequency distribution is calculated).

Equation (1) represents the model based on statistical induction. Both T_{fast} and T_{slow} depend on the conditions of the deposited radioactive cesium and the types of deposition surfaces. It is difficult to associate these elements quantitatively with the migration mechanism for radioactive cesium in the environment. T_{fast} is presumably influenced by the shielding effect of the soil as the radioactive cesium migrates deeper into the soil as well as by the reduction in radioactive cesium due to weathering, decontamination, and other forms of human activity. T_{slow} is most likely influenced by the partial retention of radioactive cesium by moisture on the deposition surface as well as by the redistribution of radioactive cesium by resuspension or human activity. T_{fast} and T_{slow} can arguably be considered similar to a distribution phase and an elimination phase, respectively.

2. Measurement Data on Dose Rates and Model Parameters

(1) Examination of ambient dose equivalent rate measurement data

The ambient dose equivalent rates measured since the accident occurred can be roughly divided into data obtained from continuous measurements at monitoring posts and other fixed positions (continuous-time data) and data obtained from irregular measurements taken using mobile instruments during vehicle-borne surveys or the like (discrete-time data). When applied in the distribution prediction model, these two types of data have both advantages and disadvantages in relation to reflecting the characteristics of the ambient dose equivalent rate distributions in terms of time and the relevant location. On the one hand, continuous-time data provides information frequently enough to allow changes in ambient dose equivalent rates in the same spot to be analyzed over time. However, these measurements are taken in a limited number of locations so they are unable to represent an extensive area. On the other hand, discrete-time data provides sufficient information for the characteristics of the ambient dose equivalent rates to be analyzed across an extensive area. However, measurements taken several times in the immediate aftermath of the accident are not sufficient to identify trends over time. For this reason, ecological half-lives were derived as one of the model parameters for developing a distribution prediction model for ambient dose equivalent rates in FY2012. The calculations were based on the results of measurements taken within 20 km of the plant by TEPCO and an emergency monitoring survey of environmental radiation by Fukushima Prefecture (continuous-time data), as well as the results of vehicle-borne surveys, airborne monitoring, and the like (discrete-time data). With about five years having passed since the accident occurred, sufficient data has been collected from extensive and frequent vehicle-borne surveys and other measurements of the ambient dose equivalent rates within the habitation zones. Such data has made it possible for us to derive and assign the appropriate model parameters for the habitation zones of local residents. **Table 1** presents the dates of the vehicle-borne surveys conducted and the number of data items used to derive and assign the model parameters. The eight vehicle-borne surveys commissioned by MEXT and the NRA were conducted within 80 km of the plant (Surveys 1–8). Other vehicle surveys were conducted inside the evacuation zones in line with a comprehensive monitoring plan (approved at the Monitoring Coordination Meeting).

Table 1 Vehicle-borne survey data

Measurement date	No. of data items
Survey 1: Jun. 4–13, 2011	42,090
Survey 2: Dec. 5–28, 2011	33,887
Survey 3: Mar. 13–30, 2012	59,037
Survey 4: Aug. 20–Oct. 12, 2012	126,249
Survey 5: Nov. 5–Dec. 12, 2012	87,991
Survey 6: Jun. 12–Aug. 8, 2013	128,270
Survey 7: Nov. 5–Dec. 12, 2013	115,985
Survey 8: Jun. 23–Aug. 8, 2014	104,630
Conducted in line with the comprehensive monitoring plan	
Trip 1: Aug. 2–30, 2011	97,512
Trip 2: Aug. 31–Oct. 9, 2011	114,971
Trip 3: Oct. 1–Nov. 4, 2011	119,660
Trip 4: Nov. 5–Dec. 12, 2011	134,376
Trip 5: Dec. 14, 2011–Jan. 30, 2012	135,724
Trip 6: Feb. 4–Mar. 10, 2012	132,692
Trip 7: Mar. 12–Apr. 16, 2012	144,644
Trip 8: May 16–Jun. 18, 2012	145,295
Trip 9: Jul. 4–Aug. 6, 2012	148,560
Trip 10: Sep. 4–Oct. 18, 2012	153,136
Trip 11: Oct. 31–Dec. 7, 2012	152,960
Trip 12: Jan. 9–Feb. 18, 2013	142,435
Trip 13: Mar. 18–Apr. 19, 2013	153,242
Trip 14: Jun. 4–Jul. 8, 2013	154,560
Trip 15: Aug. 27–Oct. 8, 2013	155,963
Trip 16: Nov. 6–Dec. 3, 2013	154,696
Trip 17: Mar. 18–Apr. 22, 2014	158,506

(2) Mesh size within 80 km of the Fukushima Daiichi NPP

Ideally, the mesh size of the model for predicting the distribution of ambient dose equivalent rates within 80 km of the plant should be the same as the zoning of data obtained from the measurements taken so far in order to ensure the convenience and reliability of the predictions. Given that ^{137}Cs has an approximate mean free path of 108 m in the air (i.e., the average distance a gamma ray travels before colliding with a molecule in the air), a mesh size of about 100 m was chosen for within 80 km of the plant. This size corresponds to one-tenth mesh of the third regional compartment adopted for vehicle-borne surveys.

(3) Assignment of initial ambient dose equivalent rates

In the distribution prediction model for ambient dose equivalent rates, any measurement data obtained from a vehicle-borne survey was applied as initial values as long as such data was available for all meshes within 80 km of the plant. Otherwise, the measurement data obtained from airborne monitoring was converted into equivalent measurement data by taking into consideration the correlations between data from vehicle-borne surveys and airborne monitoring. In either case, the assigned values were modified according to their proportion in relation to survey data from on-foot surveys to cover the habitation zones of local residents. In the evacuation zones (consisting of difficult-to-return zones, restricted residence zones, and evacuation order cancellation preparation zones), the model mainly applied the detailed monitoring results obtained from vehicle-borne surveys conducted in line with the comprehensive monitoring plan.

(4) Derivation and assignment of model parameters

In this model, the ecological half-lives of the slow-decaying component and the range of changes were adopted from values provided by the Atomic Energy Society of Japan and the Nuclear Regulatory Commission of the United States (median value: 92 years; range: 45 to 135 years) with respect to the Level 3 PRA. The ecological half-lives of the fast-decaying component and the range of changes were adopted from values derived by applying the least squares fitting method to the ambient dose equivalent rate measurement data obtained from vehicle-borne surveys. To ensure the reliability and rationality of each ecological half-life for the fast-decaying component in the evacuation zones, two types of half-lives were derived according to the land use classifications by the Advanced Land Observing Satellite (ALOS), which were for deciduous, evergreen and other types of forests as well as other areas. Beyond the evacuation zones, the half-lives were derived by conducting statistical analysis according to the ALOS land use classifications.

Table 2 presents the results of an analysis of the ecological half-lives of the fast-decaying component. The table demonstrates that these ecological half-lives in meshes classified as deciduous or evergreen forests are longer than meshes with other land uses according to the classifications used by the ALOS. In contrast, the latest analysis suggests that the half-lives do not differ significantly for different land uses according to the ALOS classifications. Instead, the difference is notable between inside and outside of the evacuation zones (the ecological half-lives of the fast-decaying component tend to be longer inside evacuation zones with less human activity compared to outside of these evacuation zones). Within a confidence interval of 90%, the statistical distribution of the ecological half-lives of the fast-decaying component could be regarded as a lognormal distribution.

The proportions of the fast-decaying component were derived for both inside and outside of the evacuation zones based on detailed monitoring data obtained from vehicle-borne surveys conducted in line with the comprehensive monitoring plan and ambient dose equivalent rate measurement data obtained from the first eight rounds of vehicle-borne surveys (Surveys 1–8). More specifically, the proportions were derived by applying a non-linear least

Table 2 Ecological half-lives of the fast-decaying component

ALOS land use classification	Half-life of fast-decaying component (year)		
	5th percentile	Median value	95th percentile
Outside evacuation zones			
Water areas	0.25	0.56	1.2
Urban areas	0.35	0.60	1.7
Paddies	0.32	0.55	1.5
Dry fields	0.32	0.63	1.9
Grass fields	0.29	0.58	2.2
Deciduous forests	0.29	0.66	2.7
Evergreen forests	0.28	0.94	5.7
Bare land	0.31	0.62	1.6
Inside evacuation zones			
Forests	0.29	0.68	3.1
Non-forest areas	0.32	0.60	1.7

squares fitting method with the initial ambient dose equivalent rates and the proportions of the fast-decaying component as the two parameters while assuming a constant ecological half-life for the fast-decaying component. The obtained proportions of the fast-decaying component were classified into forests (deciduous and evergreen) and areas under other types of land use according to the ALOS classifications in evacuation zones comprising the following: difficult-to-return zones, restricted residence zones, and evacuation order cancellation preparation zones. The proportions for outside of the evacuation zones were classified by land use according to the ALOS classifications. Subsequently, their median values and ranges were derived.

Table 3 presents the proportions of the fast-decaying component. Outside the evacuation zones, these proportions are notably different according to land use based on the ALOS classifications. In particular, the proportions in meshes classified as evergreen forests are less than those in meshes classified as urban or other land use areas. A comparison among the difficult-to-return zones, restricted residence zones, and evacuation order cancellation preparation zones that commonly comprise the evacuation zones demonstrates greater proportions and variance of the fast-decaying component in evacuation order cancellation preparation zones with relatively high levels of human activity. Within a confidence interval of 90%, the statistical distribution of all proportions of the fast-decaying component could be regarded as a normal distribution.

Table 3 Proportions of the fast-decaying component

ALOS land use classification and attributes	Proportion of fast-decaying component (-)		
	5th percentile	Median value	95th percentile
Outside evacuation zones			
Water areas	0.53	0.76	0.89
Urban areas	0.52	0.77	0.93
Paddies	0.53	0.75	0.93
Dry fields	0.48	0.71	0.89
Grass fields	0.47	0.72	0.92
Deciduous forests	0.41	0.68	0.88
Evergreen forests	0.26	0.62	0.86
Bare land	0.51	0.73	0.90
Inside evacuation zones			
Forests in difficult-to-return zones	0.32	0.45	0.55
Non-forest areas in difficult-to-return zones	0.33	0.47	0.57
Forests in restricted residence zones	0.37	0.48	0.61
Non-forest areas in restricted residence zones	0.39	0.49	0.65
Forests in evacuation order cancellation preparation zones	0.37	0.51	0.67
Non-forest areas in evacuation order cancellation preparation zones	0.29	0.51	0.69

3. Uncertainty Analysis and Validation of the Model

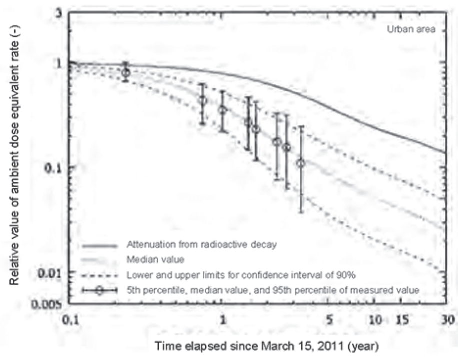
(1) Uncertainty analysis of the model

The prediction model was employed to forecast the distribution of ambient dose equivalent rates for up to 30 years following the Fukushima Daiichi Nuclear Accident both inside and outside of the evacuation zones. In the uncertainty analysis of the model, changes in the ambient dose equivalent rates were estimated using the Monte Carlo method, which considers the statistical distributions of the model's three parameters, as shown in Equation (1); in other words, the proportions of the fast-decaying component, the ecological half-lives of the fast-decaying component, and the ecological half-lives of the slow-decaying component. A uniform distribution was assumed for the statistical distribution of the ecological half-lives of the slow-decaying component based on the findings of earlier studies.

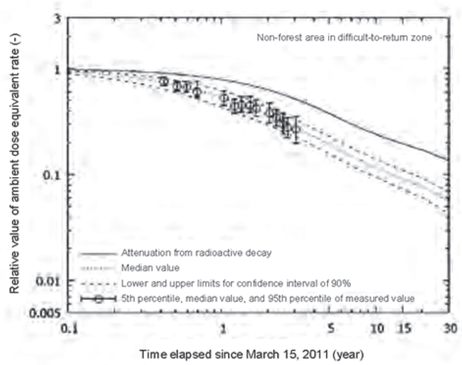
Figures 1(a) to (c) present examples of time changes in the ambient dose equivalent rates estimated using the prediction model. Figure 1(a) presents forecasts for a mesh from an urban area outside of the evacuation zones according to the ALOS land use classifications. Figure 1(b) presents forecasts for a mesh in an area not classified as a deciduous or evergreen forest in a difficult-to-return zone according to the ALOS land use classifications, while Figure 1(c) presents that for the same type of area in an evacuation order cancellation preparation zone. These figures were commonly normalized using the initial ambient dose equivalent rates, excluding the background ambient dose equivalent rates. These figures suggest that the ambient dose equivalent rates predicted by the model attenuate faster compared to scenarios in which only the decay of radioactive cesium is considered and that the attenuation is slower with less human activity. They also plot the relative values of the ambient dose equivalent rates after normalization, as well as the relative values (with each measured value being divided by the corresponding initial ambient dose equivalent rate after subtraction of the background ambient dose equivalent rate) of the measurement data for the ambient dose equivalent rates from the first eight rounds of the vehicle-borne surveys (Surveys 1–8) and up to Trip 17 of the vehicle-borne surveys conducted in line with the comprehensive monitoring plan. The relative values (median values) for the estimated ambient dose equivalent rate agree well with the ambient dose equivalent rates measured in the vehicle-borne surveys, most of which were within the estimated change ranges while taking into consideration uncertainties in relation to the model parameters.

(2) Validation of the model

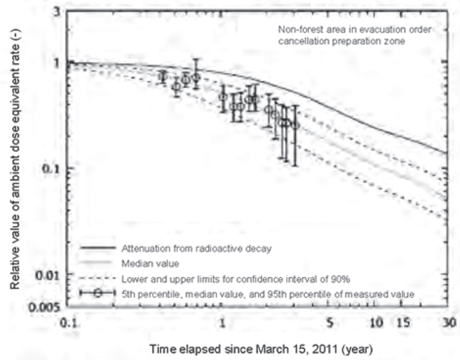
The distribution prediction model for ambient dose equivalent rates based on the measurement data obtained from the seventh vehicle-borne survey was validated by comparing the estimate results with the ambient dose equivalent rates measured in the eighth vehicle-borne survey conducted outside of the evacuation zones. The results are presented in **Figure 2**. The estimated ambient dose equivalent rates and measurements agree well within a factor of 2 for 0.1 μSv/h and greater, and their agreement improves as the ambient dose equivalent rate grows larger. The discrete trends of the distribution of the ambient dose equivalent rates within the range of around 0.1 to 0.2 μSv/h is ascribable to the effective digits of the reference measurement data used for the estimation.



(a) Outside evacuation zones (urban area)



(b) Inside evacuation zones (non-forest area in difficult-to-return zone)



(c) Inside evacuation zones (non-forest area in evacuation order cancellation preparation zone)

Figure 1 Changes in relative values of ambient dose equivalent rates over time

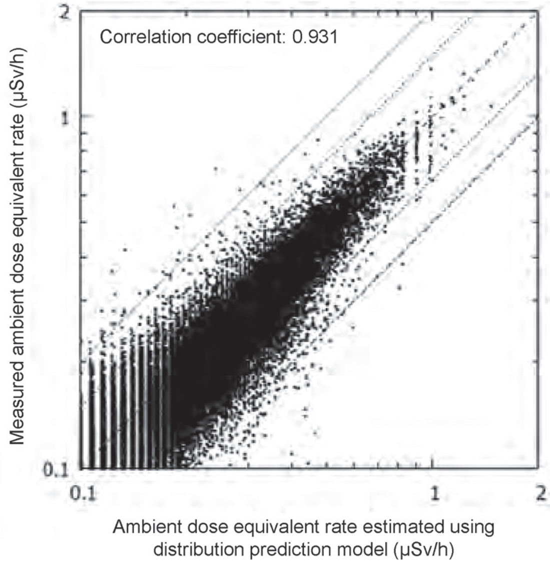
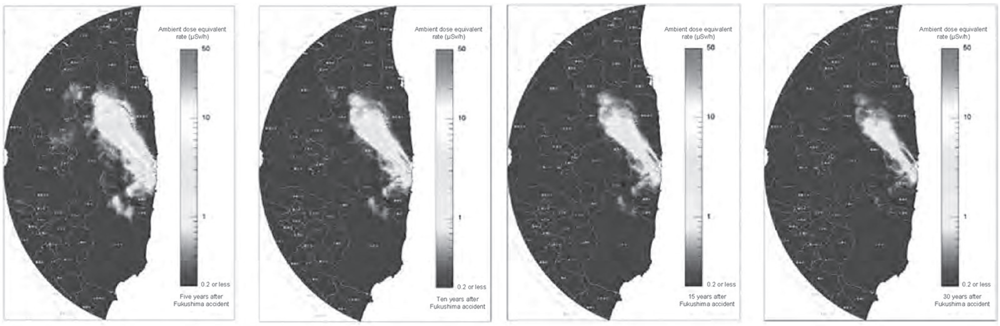


Figure 2 Comparison between ambient dose equivalent rates estimated using the distribution prediction model (based on the seventh vehicle-borne survey) and measurements taken in the eighth vehicle-borne survey

III. Forecast Maps of Ambient Dose Equivalent Rates

The physical half-life of ^{137}Cs is around 30 years. With this in mind, forecast maps of the ambient dose equivalent rates were generated for the range within 80 km of the plant after 5, 10, 15, and 30 years after the nuclear accident. The initial ambient dose equivalent rates were adopted from the measurement data obtained from the eighth vehicle-borne survey, Trip 17 of the on-vehicle survey conducted in line with the comprehensive monitoring plan, and the eighth airborne monitoring (as of November 19, 2013). The predictions were conducted in meshes for ambient dose equivalent rates (including the background ambient dose equivalent rate) of over 0.20 μSv/h by taking into account uncertainties concerning data derived using the ecological half-lives and other model parameters for the distribution prediction model. The forecast was visualized in gray scale according to the estimated levels. Meshes for ambient dose equivalent rates of less than 0.20 μSv/h are expressed using the same brightness as the level corresponding to 0.20 μSv/h. Meshes without any measurement data from airborne monitoring and vehicle-borne surveys were left blank. Examples include the waters of Lake Inawashiro and the area located within 3 km of the plant. **Figures 3**(a) to 3(d) present predictions made using the median values of the model parameters. The ambient dose equivalent rates (including the background ambient dose equivalent rate) were predicted for the habitation zones of local residents. The forecast suggested that the total area with an annual dose rate of over 20 mSv (3.8 μSv/h) would decrease within 30 years of the accident to about one-twentieth the level that prevailed five years after the accident.



(a) After five years (b) After 10 years (c) After 15 years (d) After 30 years

Figure 3 Forecast maps for the distribution of ambient dose equivalent rates

IV. Conclusions

A model was developed to predict the distribution of ambient dose equivalent rates within 80 km of the Fukushima Daiichi NPP. A forecast was made using this model for a period of up to 30 years after the nuclear accident. Because the model applies ecological half-lives and other such parameters, it can easily estimate the distribution of ambient dose equivalent rates in habitation zones both inside and outside of the evacuation zones. The model is expected to facilitate the restoration of Fukushima by helping residents to gain an understanding of radiation levels.

This commentary mainly presents the outcomes of the measurement surveys of radioactive materials commissioned by the NRA in FY2014 (consolidation of data on the distribution of radioactive materials produced by the nuclear accident that occurred at TEPCO's Fukushima Daiichi NPP and the development of a migration model). Forecast maps of the ambient dose equivalent rates were generated based on knowledge gained by the JAEA in conducting the commissioned surveys. The distribution prediction model for ambient dose equivalent rates will be revised and reviewed whenever any new measurement data or knowledge is gained.

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Impact on Marine Biota in Fukushima by TEPCO Fukushima Daiichi Nuclear Power Plant Accident

−Is fish from Fukushima Good to Eat?−

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Japan Fisheries Research and Education Agency, **Takami Morita**

The accident that occurred at the Fukushima Daiichi Nuclear Power Plant, which is operated by the Tokyo Electric Power Company (TEPCO), led to a massive release of radioactive materials into the ocean. The resultant devastation of the Japanese fishing industry continues to this day. A relatively high concentration of radioactive cesium was detected for some time after the accident. However, in the monitoring conducted subsequently by the prefectural government of Fukushima in FY2015, not a single fishery product sample exceeded 100 Bq/kg-wet, which is the national threshold for shipment restrictions. This commentary describes the current state of fishery product contamination in the waters off the coast of Fukushima Prefecture. It then explains how this contamination was reduced and examines why contamination was relatively prolonged for some fish species. It also mentions the rarely reported topic of the presence of strontium-90 in fishery products.

KEYWORDS: Fukushima accident, cesium, strontium, fishery, fishery product, reputational damage, monitoring research

I. Introduction

On March 11, 2011, an earthquake off the Pacific coast of Tohoku triggered a major tsunami that devastated TEPCO's Fukushima Daiichi Nuclear Power Plant (hereinafter referred to as the "Fukushima Daiichi NPP"). As a result, a large amount of artificial radioactive materials were released into the environment, thereby contaminating the marine biota along the Fukushima coast and in nearby waters. The devastation that this contamination has caused to the Japanese fishing industry continues to this day. In Fukushima Prefecture, a voluntary ban was imposed on all coastal fishing, except for trial fishing. From after the accident occurred until the end of February 2016, 33,753 samples of fishery products from Fukushima were examined [1]. During the period from April to June 2011, 57.7% of tested samples contained more radioactive cesium (Cs-134 and Cs-137) than the threshold of 100 Bq/kg-wet. This proportion gradually fell until eventually none of the 7,809 samples monitored between April 2015 and

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the end of February 2016 exceeded this threshold. However, given the repeated media coverage of contaminated water, concerns over the safety of local fishery products from Fukushima have yet to be dispelled. The resumption of fishing in Fukushima remains out of sight because of the lasting reputational damage caused by such coverage.

II. Radioactive Cesium in Fishery Products

1. Uptake and Elimination [2)]

Cesium is a water-soluble alkali metal element that behaves similarly to potassium, which is another type of alkali metal. Just like potassium, cesium is eliminated from the body so, after its uptake by fish, radioactive cesium does not accumulate in sufficient quantities to be detected in high concentrations years later. The uptake of radioactive cesium by fish takes place through two channels: the intake of food organisms and the uptake from ambient water. Different proportions have been reported for these two channels, with the uptake from ambient water ranging from 30 to 50%. The contribution from ambient water never exceeds that from food organisms. It is unclear whether radioactive cesium from food organisms and that from ambient water behave differently inside fish, but it is evident that radioactive cesium is dissolved in body fluids in an ionized form.

Osmoregulatory mechanism in fish significantly influences the uptake and elimination of radioactive cesium. Fish try to maintain a constant body environment within a certain physiological range to sustain their vital activities, and fish that regulate osmotic pressure are classified as osmoregulators. Marine fish live in seawater with a higher salt concentration than their body fluids, so they are passively deprived of water in their bodies due to osmotic pressure. To offset this loss, marine fish try to replenish their body water by swallowing seawater. They maintain a constant salt concentration in their bodies by actively pumping potassium and sodium out via chloride cells in their gills or by excreting them with a small amount of urine. Radioactive cesium is also eliminated during this process.

Some invertebrates that inhabit brackish waters or other changing environments are osmoregulators. However, most other marine invertebrates (e.g., squid, octopuses, shellfish, shrimps, and crabs) are osmoconformers, which keep their body fluids almost osmotic relative to the ambient seawater [2)]. Therefore, the radioactive cesium concentration in these species drops quickly following any reduction in the radioactive cesium concentration in seawater. Unlike terrestrial plants, seaweed absorbs nutrients from seawater, not from the marine soil. Accordingly, the radioactive cesium concentration in seaweed drops following any reduction in the radioactive cesium concentration in seawater.

2. Radioactive Cesium Concentration in Fishery Products

(1) Radioactive cesium concentration among species other than demersal fish

Sardines, saury, and other fish that always stay above the bottom of the sea are called pelagic fish. In contrast, demersal fish, such as righteye and lefteye flounders, maintain contact with the bottom of the sea.

The radioactive cesium concentration in pelagic fish depends on the concentration in the ambient seawater (because the concentration in their food organisms also depends on the ambient seawater). Therefore, any reduction in the radioactive cesium concentration in seawater gradually reduces the concentration in the bodies of pelagic fish. The leakage of highly contaminated water into the ocean due to the Fukushima Accident was relatively short time, so this water was quickly diluted and dispersed in the ocean. A major portion of the radioactive cesium dropped out of the element cycle in the surface seawater along with settling particles. As a result, the radioactive cesium concentration in seawater dropped sharply. On May 13, 2011, for example, swarms of whitebait (immature sardines) near the surface of the sea off the Fukushima coast contained 850 Bq/kg-wet of radioactive cesium, but this measurement had already dropped below the detection limit of 5 Bq/kg-wet by September 14, 2011 [1].

The radioactive cesium concentration in the bodies of invertebrates and seaweed also dropped quickly because the level depends on the ambient seawater, as explained earlier. These species are probably affected by radioactive cesium in marine soil similarly to demersal fish (discussed later). Unlike fish, however, they are osmoconformers that easily release radioactive cesium, so the concentration in their bodies probably dropped swiftly. The trial fishing for octopuses and shellfish described later was conducted in Fukushima based on the monitoring data and biological knowledge presented so far.

(2) Radioactive cesium concentration among demersal fish

The radioactive cesium concentration in demersal fish, such as righteye and lefteye flounders, tends to drop considerably slower compared to pelagic fish [1, 2]. This slower rate of reduction clearly indicates the continued uptake of radioactive cesium by demersal fish, but details of the uptake channels are not known. The discovery that lefteye flounders and black seabream kept in a tank with highly contaminated marine soil do not carry a high concentration of radioactive cesium demonstrates that demersal fish are not directly contaminated by marine soil. Even the food organisms raised in such a tank did not accumulate a high concentration of radioactive cesium [3]. The presumed reason for this is the scarce release of radioactive cesium adsorbed by clay minerals in marine soil. The presence of organic matter with a high concentration of radioactive cesium has also been confirmed for marine soil [3]. This organic matter is a likely source of contamination that slows down the reduction in the radioactive cesium concentration among demersal fish. However, the exact contamination mechanism has yet to be understood. In addition to the possible intake of such organic matter through food organisms, demersal fish may be directly taking in organic matter that drifts near the bottom of the sea due to sediment resuspension.

It is important to clarify here that the assumed continuous uptake by demersal fish does not increase the level of radioactive cesium concentration in their bodies. It simply slows down the reduction. Not long ago, misinformation claiming that the radioactive cesium concentration does not decrease was widespread. The source of this misinformation is believed to be an article published in a well-known scientific magazine that featured monitoring data from FY2011 [4]. The monitoring survey was not conducted within 30 km of the Fukushima Daiichi NPP until the designated emergency evacuation preparation zone was lifted (for a range of between 20 and 30 km) on September 30, 2011. The monitoring survey began after September 30, 2011 within a range of between 20 and 30 km from the plant. The survey sites gradually shifted to within 20 km, and this shift is most likely the reason why the concentration in demersal fish seemingly did not decrease (**Figure 1**).

A recent study has also found that fish born after the accident have a lower level of contamination [3]. This finding demonstrates that a major contributor to the contamination of fishery products from Fukushima was the release of highly contaminated water in the aftermath of the accident and that further contamination is no longer underway. The level of contamination of fishery products is expected to diminish further as the proportion of fish born after the accident increases.

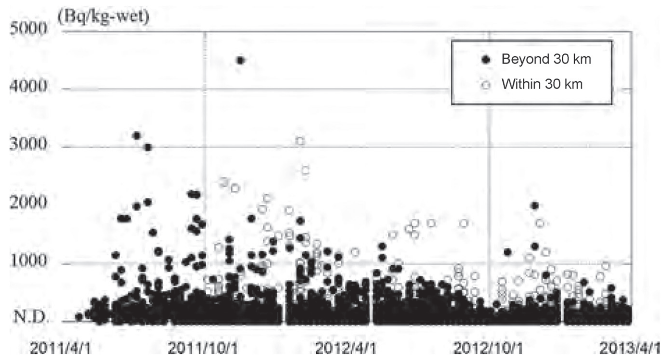

Figure 1 Concentration of radioactive cesium in demersal fish from Fukushima
The data cited here was obtained from a reference document [1]. N.D. denotes a level below the lower detection limit.

3. Characteristics of Radioactive Cesium Contamination of Fishery Products

(1) Behavior of radioactive cesium in an ecosystem

It is generally believed that contaminants become concentrated in a higher trophic level through food chains. However, a high level of concentration with a factor of 100 does not occur for radioactive cesium and other water-soluble substances because they are eliminated at each trophic level through the mechanisms explained earlier. Compared to the reported concentration factor of polychlorinated biphenyls (PCB), which is in the order of between tens of thousands to hundreds of thousands, radioactive cesium clearly presents a much lower level of concentration. Meanwhile, the Act on the Regulation of Manufacture and Evaluation of Chemical Substances defines the bioaccumulation of substances with a factor of 5,000 or more. Some claimed that tuna in a higher trophic level would be highly contaminated a few months after the Fukushima Accident. However, since the leakage of highly contaminated water had already been stopped, this claim was dismissed at an early stage [5]. In fact, the highest level of concentration in tuna caught off the Fukushima coast was 41 Bq/kg-wet according to information published in October 2011 [1]. In contrast, the nature of heavy metals with induced radioactivity from nuclear experiments (e.g., manganese-54, iron-55, iron-59, and zinc-65) means that they are known to bioaccumulate along food chains [6].

(2) Nonuniform contamination [6, 7]

The Fukushima Accident can be characterized by the nonuniformity of the resultant contamination. This can be attributed to the following three factors.

A. The contamination source is located in Japan.
B. Highly concentrated water leaked directly into the ocean.
C. The majority of the leakage was stopped relatively quickly.

Factor A resulted in different levels of contamination according to the distance from the source. Natural phenomena (i.e., ocean currents in this case) led people to make assumptions such as that rockfish off the northern coast of Fukushima would be contaminated to a similar degree as rockfish in the south, which were found to have a high concentration of radioactive cesium. It was also assumed that contaminated species from Fukushima had been contaminated in other prefectures, resulting in reputational damage.

Factor B brought some fish into direct contact with highly contaminated water. As a result, the concentration varied significantly among different bodies of fish in the same species caught in the same water areas. This fact raised widespread concerns that highly

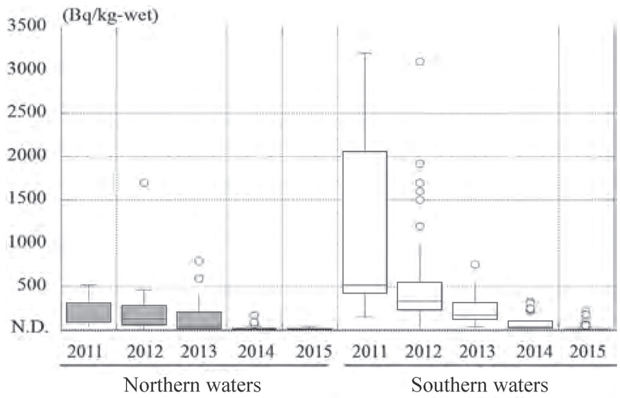

Figure 2 Radioactive cesium concentrations among rockfish in the north and south of the Fukushima Daiichi NPP
The data cited here was obtained from a reference document [1]. N.D. denotes a level below the lower detection limit.

contaminated fish may be overlooked in a sampling survey.

Factor C led to a sharp drop in the concentration of radioactive cesium owing to its swift dilution and dispersion in the ocean. Despite a steady drop in the concentration of radioactive cesium in fishery products under the mechanism mentioned earlier, the stigma of contamination lingers on. As an example of this, **Figure 2** presents the distribution of the levels of radioactive cesium concentration among rockfish off the Fukushima coast. This figure clearly indicates a higher concentration in the southern waters due to ocean currents carrying highly contaminated water southward (Factor A). Figure 2 also demonstrates a high degree of variance among samples. The degree of contamination in different places is not evened out by the mingling of fish, because rockfish and other fish that tend to dwell near rocks do not migrate over long distances. Therefore, the distribution of contamination levels in the immediate aftermath of the accident is believed to have remained unchanged (Factor B). Nonetheless, the radioactive cesium concentration is on the decline even among rockfish, a type of fish that is often mentioned as a notable example of contamination (Factor C).

III. Reputational Damage

1. Strontium-90

One of the most frequently raised concerns is that inspections of fishery products are conducted with respect to radioactive cesium but not with respect to strontium-90. It is certainly true that only the radioactive cesium concentration is indicated according to existing food safety standards. However, these standards are prepared by assuming the presence of a certain amount of radioactive materials with a half-life of 1 year or more (plutonium, strontium-90, and ruthenium-106) that were presumed to have been released in the Fukushima Accident [6, 8]. These standards are prepared based on the assumption of an equivalent dose of these nuclides as that of radioactive cesium in fishery products. The studies conducted to date have revealed that the assumed level is actually too high. Despite the fact that the standards give due consideration to strontium-90, there were reasonable concerns that a lack of measurements may cause unwarranted reputational damage. In response to a request from the

Fisheries Agency, the Japan Fisheries Research and Education Agency began measuring radioactive strontium in May 2011. These measurements are published online[9]. TEPCO also began measuring the concentration of strontium-90 within a range of 20 km from the Fukushima Daiichi NPP. So far, the measured dose ratios for strontium-90 and radioactive cesium fall within the range of between 0.00018 and 0.016. This finding proves that there is no need for concern over food safety since the ratio is much lower than that assumed in the setting of the existing standards[8].

2. Misconceptions about Contaminated Water

One other reason for lingering consumer concerns about the contamination of fishery products is the repeated media coverage of the leakage of contaminated water from the Fukushima Daiichi NPP. In August 2013, TEPCO announced that it had been continuously releasing radioactive cesium and other radioactive materials since the accident. The total amount of radioactive cesium (during a period of 850 days) was about one hundredth of the amount leaked over the course of 10 days in April 2011 in the immediate aftermath of the accident. This release was found to have had an impact only in the port exclusively reserved for the plant. Beyond this area, the release was found to have had no impact at all, even in the waters used for conducting trial fishing. The media also reported the leakage of contaminated water from an onshore tank and the leakage of contaminated rainwater into the ocean through drainage systems. However, none of these incidents has ever caused a rise in the concentration of radioactive cesium in fishery products caught off the Fukushima coast.

Radioactive materials are initially introduced into the food webs of an ecosystem through ambient water. The extent of the ultimate concentration of radioactive materials in living organisms compared to the concentration in ambient water is expressed by the concentration factor (concentration in the body / concentration in seawater)[2]. Since the Fukushima Accident, it has become widely known that the concentration factor of radioactive cesium in marine fish is about 100 at most. To correct a common misunderstanding, it is important to note that fish swimming in seawater with a radioactive cesium concentration of 1 Bq/L will not necessarily have a concentration of 100 Bq/kg-wet in their bodies. In this environment, a food chain with food organisms that have taken in radioactive cesium must exist in order for fish to eat them and thus gain a concentration level according to the given factor[8]. Some people have suggested that fish will have a radioactive cesium concentration of 100 Bq/kg-wet after simply swimming through the waters near the port for the Fukushima Daiichi NPP, which has a concentration of 1 Bq/L. Such people are mistaken. In some cases, even correct statements made by researchers can cause reputational damage. Researchers are keenly interested in the possible causes of any increase in the waterborne concentration of radioactive materials in the order of several hundreds of mBq/L from an original level of several Bq/L. However, changes of this type of magnitude do not change the concentration in fishery products significantly enough to affect our health. Comments made by presumably knowledgeable researchers that are published in newspapers or magazines with an apparently strong interest in such changes tend to be interpreted by the public as having critical implications for their health.

3. Insufficient Understanding of the Actual Situation

Some people believe that the leakage of contaminated water with a high concentration of radioactive materials led to the appearance of deformed fish. The author and his colleagues have regular access to the fish sampled as part of the expulsion in the port for the Fukushima

Daiichi NPP, but they have not identified any that are deformed. Calculations also indicate that such deformations are highly unlikely [2]. In fact, the only fish that the author has seen become deformed due to radioactive contamination is Blinky from the American animated sitcom The Simpsons. Furthermore, the author has also requested samples of fish caught in ports from some Japanese research institutes that are considered well informed about radiation damage, but none of them has offered to conduct any studies. Fish and shellfish lay a vast number of eggs, but only a few of them survive in natural marine waters. Even if some of them become deformed due to radiation during their early development, they are extremely unlikely to survive. Their contribution to the reproduction of their species is almost inconceivable. The voluntary ban on fishing in Fukushima has reportedly resulted in an increase in the fishery stocks.

A high concentration of radioactive cesium was detected in fat greenling caught in 2012. The author and his colleagues published a paper ascribing this high concentration to contamination in the immediate aftermath of the accident [3]. In its report published in October 2015, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) quoted our paper. In the English original, the report mentioned that the concentration of radioactive cesium remained high among fat greenling. However, the Japanese version that they published simultaneously stated the following: “The radioactive cesium concentration among fat greenling is still on the increase.” The author noticed this mistranslation and contacted the UNSCEAR Secretariat, which is based in Vienna, in November 2015 to request a correction. They eventually corrected this part of the report in February 2016 [10]. The mistranslation was reportedly made by a translation agency. However, the Japanese involved in preparing this report should also have felt uncomfortable with this discrepancy if they accurately understood the actual state of fishery product contamination. Those in charge of preparing such a report most probably have more information than the public, so it is extremely regrettable that even they were not well informed of the actual state of contamination. Because the use of the present tense in this kind of report can be misleading, it should be pointed out that the concentration of radioactive cesium in fat greenling monitored in Fukushima never exceeded 40 Bq/kg-wet in FY2015 [1].

IV. Current State and Future of the Fishing Industry

1. Survey of Fishery Products on the Market

The concentration of radioactive cesium in fishery products from Fukushima is on a steady decline. However, fishery products that satisfy the relevant safety standards must be traded among brokers, handled by processing companies, and ultimately purchased by consumers. Otherwise, the fishing industry is not viable. Although only trial fishing is being conducted in Fukushima Prefecture at present, monitoring inspections have been conducted with many samples and the results have been published. These results are often confused with those of inspections of fish on the market, but the fish were caught exclusively to conduct monitoring inspections. They are not put on the market. Foods on the market are regularly inspected by the Ministry of Health, Labour and Welfare. From the occurrence of the Fukushima Accident until the present day (end of March 2016), fishery products on the market that have exceeded the threshold were detected only twice in 2012. This is extremely rare compared to the 30 such cases among agricultural and livestock products, especially considering that most fishery products are wild caught [8, 9]. Fishing activities have been suspended for some time along the Pacific side of Eastern Japan, which was seriously affected by the Fukushima Accident on top of the devastation left by the tsunami that was triggered by the Great East Japan Earthquake. Fishing activities have been resumed one by one after first confirming their safety by conducting inspections for radioactive materials (positive list system). In contrast, shipments of agricultural products continued from inland areas less affected by the tsunami even after the Fukushima Accident. Shipment restrictions were imposed only on products that exceeded the safety limits (negative list system). Although the total amount is unknown, it is easy to imagine that many products that exceeded the safety limits were put on the market. The contamination of beef and shiitake was mostly caused by the distribution of contaminated rice straw and logs, respectively. Farmed fish are raised in similarly controlled environments, but the Fisheries Agency immediately provided guidance to aquaculturalists on how to prevent contamination and related groups stopped the distribution of feed that may be contaminated. For this reason, no inspected farmed fish (excluding extensively farmed ones) exceeded the safety limits [1].

2. Fishing Industry in Fukushima Prefecture

Immediately after the Fukushima Accident, the Fukushima Federation of Fisheries Cooperatives organized a meeting of cooperative leaders on March 15, 2011. At the meeting, they decided to impose a voluntary ban on fishing activities along and off the Fukushima coast. To date, marine fishing activities have remained suspended, except for trial fishing (discussed later). This voluntary ban was imposed purely based on the judgment of the fisheries industry without any instructions to that effect being issued by the national or local governments.

At present (i.e., the end of March 2016), shipment restrictions have been imposed on 28 types of fish from Fukushima. However, this does not necessarily mean that they still have a high concentration of radioactive cesium. Begun in Fukushima off the coast of Soma and Futaba (approx. depth: 150 m) in June 2012, trial fishing was conducted for several months for species whose radioactive cesium concentration was at or below the lower detection limit (2–3 Bq/kg). This trial fishing began with three species off the coast of Soma and Futaba, but the number of target species has increased (73 as of the end of March 2016) along with the expansion of the target waters to include an area off the coast of Iwaki. However, due to reputational damage and other difficulties, only a few businesses trade in fishery products from Fukushima and a return to full-scale fishing operations remains out of sight. Incidentally, the waters located within 20 km of the Fukushima Daiichi NPP are excluded from the trial fishing, but the monitoring survey did not identify any differences in concentration between the waters within and beyond the range of 20 km, except for in areas inside the port or very near the plant. These waters are not targeted in the trial fishing to ensure the safety of the fishery products caught during the trial fishing.

3. Future of the Fishing Industry in Fukushima Prefecture

As mentioned earlier, the concentration of radioactive cesium in fishery products is on a steady decline. Furthermore, the inspection system is fully functional. Nonetheless, consumers remain concerned about the contamination of fishery products, and some neighboring countries still impose rigorous import restrictions. Consumers have not received any updated information since they were made aware of the awful conditions that prevailed in the immediate aftermath of the Fukushima Accident. Perhaps the repeated media coverage on the leakage of contaminated water from the Fukushima Daiichi NPP has ingrained this outdated knowledge. Otherwise, they would find it hard to accept the actual situation in light of the noticeable gap between the severe contamination that existed in the immediate aftermath of the accident and the much lower level of contamination that prevails today.

In FY2015, significant progress was made in relation to measures for dealing with contaminated water. Examples of these measures include the removal of highly contaminated water from the trenches for seawater piping at the Fukushima Daiichi NPP, the performance of coating work for the seabed inside the port, the completion of a seaward impermeable wall, and the deployment of a frozen soil wall. The author hopes that the press will report such improvements.

Statistical calculations have already demonstrated that the chance of fishery products from Fukushima exceeding the safety limit is just one in ten thousand [9)]. Furthermore, there is scientific evidence for the reduced level of contamination in fishery products. To counter the reputational damage, we believe it is important to not only monitor the concentration of radioactive materials in fishery products, but also offer a clear and scientific explanation of how they become contaminated and how such contamination can be mitigated. The Japan Fisheries Research and Education Agency strives to communicate accurate information through its website and publications [3, 8, 9)]. We hope that you will refer to these resources.

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Commentary

Movements and Storages of Radiocesium in a Forest Ecosystem in Fukushima

Kyoto University, **Nobuhito Ohte**

The disaster that occurred at the Fukushima Daiichi Nuclear Power Plant in March 2011 resulted in a massive dispersion of radioactive cesium (^{137}Cs) over vast forests and other surrounding areas. The author has conducted intensive monitoring in a water catchment area located in northern Fukushima to determine and explain how exactly ^{137}Cs migrates to and builds up in a forest ecosystem before being discharged from it. This monitoring revealed that the amount of ^{137}Cs that is discharged from the forest over the course of one year was at least two orders of magnitude less than the estimated amount of deposition immediately after the disaster. It has been suggested that the migration takes place mainly in the form of suspended solids with particulate organics serving as important carriers. The largest ^{137}Cs pools in the forest ecosystem proved to be the litter layer and the topsoil. The circulation of ^{137}Cs was also indicated within flora, including tall trees. The dispersion of ^{137}Cs within the biological communities of animals and other creatures was more notable in terms of migration through food webs extending from animals that feed on fallen leaves and their fragments as compared to migration through food webs extending from animals that feed on live leaves. No increase in the ^{137}Cs concentration was observed with the rise in the trophic level, which demonstrates that no biological accumulation took place.

KEYWORDS: Fukushima, radioactive cesium, forest ecosystem, biogeochemical cycle, suspended solid, food web, biological accumulation, root absorption

I. Introduction

The accident that occurred at the Fukushima Daiichi Nuclear Power Plant in March 2011 resulted in a massive dispersion of radioiodine (approx. 1.5×10^{17} Bq of ^{131}I) and radioactive cesium (approx. 1.2×10^{16} Bq of ^{137}Cs) in Fukushima and its surrounding areas [1]. The forest coverage exceeds 70 percent in most municipalities within these areas. The deposited radioactive materials raise concerns in terms of exposure in human habitats, damage to the forestry and forest product industries, and impairment of water sources in forests.

The initial survey, which was led by the Ministry of Education, Culture, Sports, Science

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and Technology (MEXT) and the Ministry of Agriculture, Forestry and Fisheries (MAFF) soon after the deposition began in FY2011, indicated that the radioactive cesium that fell on forests was retained on the crowns of evergreen trees and in the litter layer around deciduous trees [1, 2]. It has been indicated that clay minerals in soil strongly adsorb radioactive cesium [3]. It has also been reported that radioactive cesium is discharged into streams and rivers along with soil particles due to any soil erosion and runoff (e.g., Wakiyama et al., 2010) [4].

In a forest ecosystem, the radioactive cesium deposited on tree crowns migrates toward the forest floor over time by means of eluviation caused by rain [5] or defoliation [6, 7]. Hashimoto et al. [2] conducted a numerical simulation based on data obtained up to 2012, and they predicted that most of the radioactive cesium that was deposited on the tree crowns would reach the forest bed within the first five years.

Dissolved radioactive cesium is absorbed by microbes, algae, plants, and various other creatures in a forest ecosystem. In a biological community, the radioactive cesium captured by algae, plants, and other primary producers is most likely passed along a food web to a wide range of creatures. Ultimately, it is likely to move up the trophic levels to fish, birds, and mammals. Many past studies on the migration of radioactive substances through food webs have attempted to determine whether biological accumulation takes place [8, 9].

To deal with forest contamination in the affected areas, it was considered essential to clarify in detail how radioactive cesium deposited in forests is redistributed by migration within the ecosystem and how much of the radioactive cesium is discharged from the system in the initial years. Accordingly, the author and his colleagues conducted a survey in a forest located in northern Fukushima with the following aims: 1) to determine the redistribution mechanism for radioactive cesium in the forest; 2) to assess the amount of radioactive cesium that flows down streams in the hydrological process; and 3) to monitor radioactive cesium migration among creatures in the food web of the biological community. This paper reports the survey results using data obtained by the end of FY2014 to consider necessary surveys and measures for the future. It may be noted that most of the findings have already been published in the references [10-12].

II. Survey Method

A field survey was conducted at the gully head of the Kami-Oguni River, which runs through the Kami-Oguni district of Ryozenmachi, Date City, in northern Fukushima. According to aircraft observations conducted in June and July of 2013, the air dose rate in the surrounding area ranged from 1.0 to 1.9 μSv h^{-1} and the expected total amount of ^{137}Cs precipitation was between 100 and 300 kBq m^{-2} [13]. The main parts of the survey site are covered by a mixed secondary forest made up of Japanese red pine (*Pinus densiflora*) and deciduous broadleaf trees, such as jolcham oak (*Quercus serrata*) and Japanese elm (*Zelkova serrata*). An approximately 50-year-old artificial forest of Japanese cedar (*Cryptomeria japonica*) extends along the valley.

To track the flux from the radioactive cesium that migrates along with water in these forests, a hydrological observation was conducted to measure the radioactive cesium concentration at various stages from the precipitation to the runoff (e.g., precipitation, passage through crowns, and spillover into streams). Two square plots were assigned to the mixed forest of deciduous broadleaf trees and Japanese red pine as the main part of the forest system. Another plot was assigned to the artificial forest of Japanese cedar. In each of these plots, the litterfall (i.e., fallen leaves and branches in a forest) was sampled, and measurements were taken to determine the amount and concentration of radioactive cesium in the throughfall and stemflow.

In addition, land and aquatic creatures were sampled along the stream to determine the extent to which radioactive cesium is transmitted within the biological community. The sampled creatures were identified before the concentration of radioactive cesium in their tissues was measured.

Moreover, standing trees in the main forest were cut down and sampled in November of both 2012 and 2013 to estimate the amount of radioactive cesium buildup above the ground. The samples were divided into live leaves, branches, and trunks (bark, sapwood, and heartwood) to measure the radioactive cesium concentration [10, 11].

III. Results and Discussion

1. ^{137}Cs Concentration in Plants

Live leaves on evergreen Japanese cedar can last for about three years. The leaves that foliate in the current year are called “current leaves,” while other leaves that foliated earlier are called “older leaves.” Presumably, a certain proportion of the leaves were still attached in the years that followed the deposition of radioactive cesium on them in March 2011. In 2012, the ^{137}Cs concentration in live leaves exceeded 10,000 Bq kg^{-1} for both current leaves and older leaves. The concentration measured in 2013 had dropped to 3,500 Bq kg^{-1} in older leaves and 2,700 Bq kg^{-1} in current leaves (**Figure 1**). The similar concentration levels observed between leaves that foliated in 2012 and leaves that remained from the previous year suggest that the deposited radioactive cesium was translocated from the crown or other parts of the trees to newly formed leaves. This means that radioactive cesium on the surface of leaves, branches, and trunks can seep into the tree body and that it can be carried via nutrient translocation inside the tree body. The decline in the ^{137}Cs concentration that was observed with older leaves in 2013 can probably be explained by them being replaced with new leaves that have a relatively low concentration and rainfall washing away some of the radioactive cesium.

As a deciduous tree, jolcham oak foliates in early summer and defoliates in late fall, which means that live leaves on the crown are replaced every year. The ^{137}Cs concentration in live leaves was around 1,000 Bq kg^{-1} in both 2012 and 2013. In March 2011, when radioactive cesium first fell on the forest, live leaves had not foliated yet. The ^{137}Cs in these samples seems to have seeped into the tree body from the surface of the trunks and branches before further translocation. Meanwhile, some of the ^{137}Cs that was deposited on fallen leaves and the like on the forest floor was absorbed through roots before being transferred to new leaves.

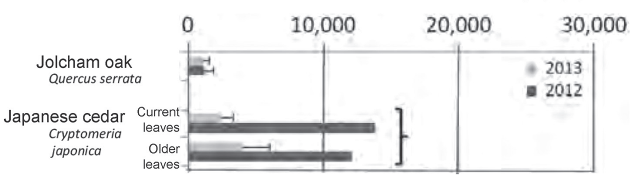

Figure 1 ^{137}Cs concentration in live leaves on jolcham oak and Japanese cedar
The samples were taken by cutting down standing trees in November of both 2012 and 2013. The concentration was measured separately for older leaves and current leaves on Japanese cedar (Ohte et al., 2015 [11]).

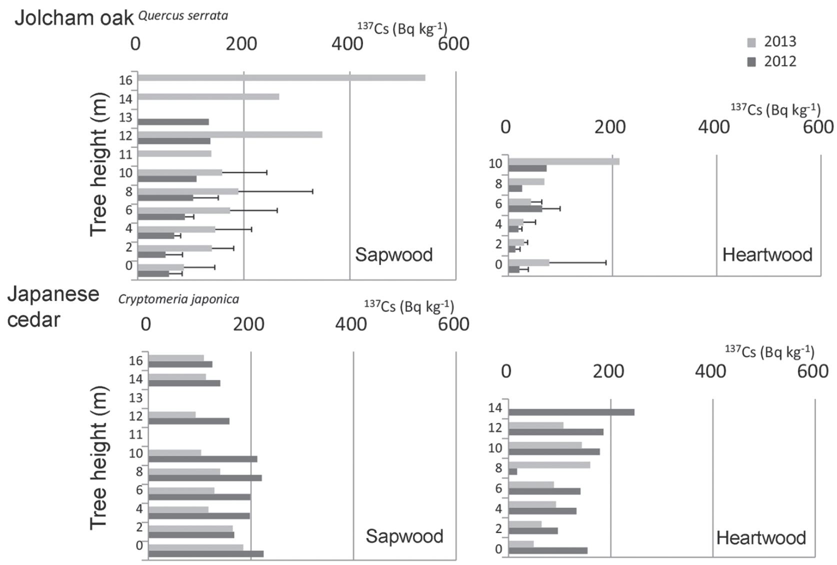

Figure 2 ^{137}Cs concentration in the sapwood and heartwood of Japanese cedar and jolcham oak
The samples were taken by cutting down standing trees in November of both 2012 and 2013 (Ohte et al., 2015 [11]).

The ^{137}Cs concentration exceeded 10,000 Bq kg^{-1} in most bark samples from jolcham oak during the same period in 2012 [11].

The marginal difference in concentration between the sapwood and the heartwood of Japanese cedar as compared to jolcham oak in both 2012 and 2013 (**Figure 2**) indicates a much faster translocation of radioactive cesium in a tree trunk of Japanese cedar.

The above findings demonstrate the active movement of radioactive cesium via the nutrient translocation mechanism of trees. Especially, the discovery that a high concentration of radioactive cesium in bark migrates to sapwood and then translocates to leaves is important. The next task would be to conduct a quantitative measurement of the ^{137}Cs absorption through roots under a forest floor covered in heavily contaminated leaves.

2. Migration of Radioactive Cesium from Tree Crowns to the Forest Floor

Among the three plots, the greatest migration of ^{137}Cs from tree crowns to the forest floor via litterfall was observed in the artificial cedar forest (**Table 1**) [14]. As explained in the previous section, this is probably due to the larger amount of radioactive cesium that was deposited on evergreen tree crowns. Even when the throughflow and stemflow were taken into consideration in addition to migration via litterfall, the amount of migration was found to be greatest in the artificial forest of evergreen cedar.

The migration from the tree crowns to the forest floor supplies ^{137}Cs to microbes in the litter and humus layers as well as to the plants that extend their roots there. However, the availability of ^{137}Cs for microbes and plants is believed to be quite different between migration via litterfall and migration via throughfall and stemflow.

In addition to confirming the amount absorbed by trees through their roots as mentioned earlier, detailed surveys need to be conducted to determine the standing stock of radioactive cesium in the upper-litter and humus layers that is readily absorbable by plants and microbes as well as other factors such as seasonal changes in the standing stock of radioactive cesium.

Table 1 Annual average ^{137}Cs concentration and annual ^{137}Cs flux for throughfall, stemflow, and litterfall

	Annual average ^{137}Cs concentration (Bq L^{-1}: Throughfall and stemflow; Bq kg^{-1}: Litterfall)			^{137}Cs flux (Bq m^{-2} $year^{-1}$)		
	DP1	DP2	CP	DP1	DP2	CP
Throughfall	3.10	3.01	5.54	3,254	1,694	3,388
Stemflow	4.01	0.97	2.16	458	101	69
Litterfall	8,068	7,464	17,887	2,904	2,125	7,518

Footnote: DP1: Mixed forest of deciduous broadleaf trees and Japanese red pine trees 1; DP2: Mixed forest of deciduous broadleaf trees and Japanese red pine trees 2; CP: Artificial forest of Japanese cedar. (Original data source: Endo et al., 2015 [14])

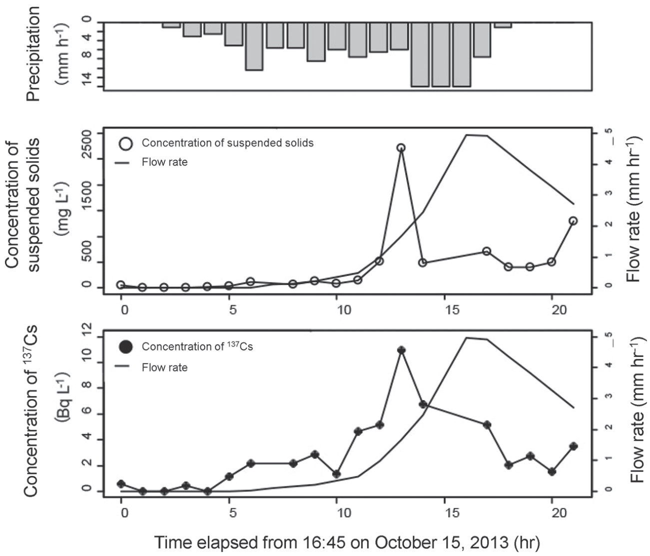

Figure 3 Precipitation, concentration of suspended solids, concentration of ^{137}Cs, and river flow over time during a flooding event on October 15, 2013 (Iseda, 2015 [15])

3. Radioactive Cesium Runoff into Streams

Figure 3 presents changes in the concentrations of suspended solids and ^{137}Cs over time during their rain-induced runoff into a swollen stream in October 2013 (Iseda, 2015) [15]. These changes are almost synchronized, which indicates that suspended solids served as important carriers for ^{137}Cs runoff.

The annual ^{137}Cs runoff from the catchment area was estimated by taking into consideration the changes in ^{137}Cs concentration associated with changes in the stream's flow rate. The estimated amount for the period from August 31, 2012, to August 30, 2013, was 330 Bq m^{-2} $year^{-1}$ [15]. However, it should be noted that just one major flood caused by heavy rain in mid-October 2013 caused a ^{137}Cs runoff of 227 Bq m^{-2} in a matter of a few days. Given this, it is quite important to observe flooding to track the ^{137}Cs runoff from the catchment area accurately.

As mentioned earlier, the estimated ^{137}Cs deposition in this area is 100 to 300 kBq m^{-2}, which is three orders of magnitude greater than the estimated runoff in a period of one year.

Given ^{137}Cs's half-life of roughly 30.1 years, the amount of radioactive cesium that is discharged from a forest ecosystem into rivers through hydrological processes is apparently much less than the amount that disappears due to radioactive decay within the system.

4. Migration of Radioactive Cesium in Food Webs

Figure 4 presents the ^{137}Cs concentration among samples of land and aquatic creatures broken down by functional group. The concentration for fallen leaves, fungi, scavengers, and predators was significantly higher than that for the live leaves on plants and plant-eating creatures.

Fallen leaves and their fragments that have built up on the ground surface retain the largest amount of ^{137}Cs, which migrated noticeably among land creatures from these sources. Fallen leaves and their fragments and benthic algae, which serve as basic food for aquatic creatures, had ^{137}Cs concentration levels that were somewhere between the concentration levels for live leaves and those for fallen leaves on the ground. The ^{137}Cs concentrations among creatures in higher trophic levels could be explained by a combination of the concentration levels explained earlier [16].

The nitrogen stable isotope ratio increases in the tissues of creatures in higher trophic levels, so it can be regarded as a relative indicator of tropic levels. The measured ratio and the ^{137}Cs concentration among creature samples exhibited a slightly negative correlation. In other words, the ^{137}Cs concentration was lower among creatures in higher trophic levels, which indicates that no biological accumulation of ^{137}Cs took place in the biological community studied in this survey [16].

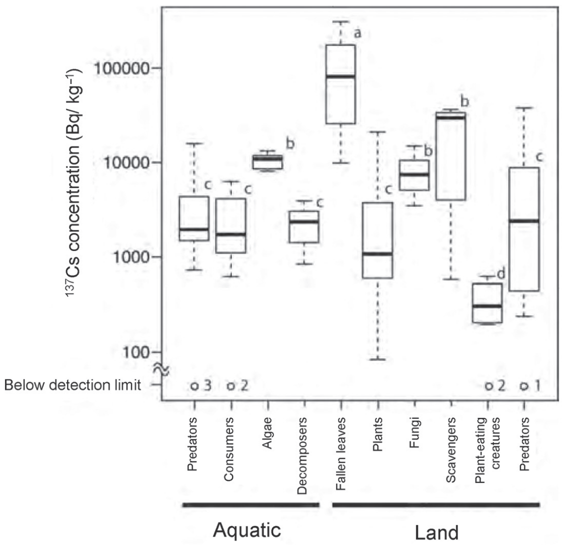

Figure 4 ^{137}Cs concentration by functional group
The alphabetic denotation assigned to each plot represents its functional group according to the statistical grouping. The same letter represents the same functional group. There were samples below detection limit for predators and consumers in aquatic, plant-eating creatures and predators in land. The number of those samples is indicated after circle (Murakami et al. 2014 [16]).

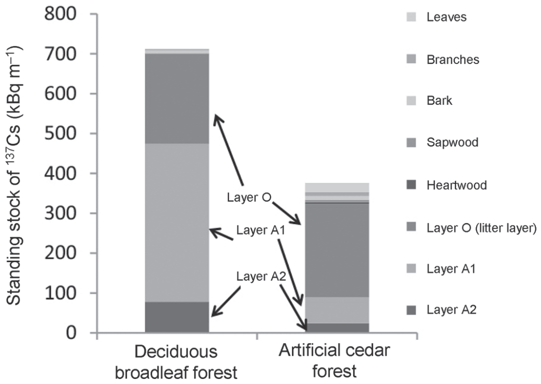

Figure 5 Distribution of the standing stock of ^{137}Cs among parts of the plots covered respectively by a deciduous broadleaf forest and an artificial cedar forest as of September 2014 (yet to be published) Layer O represents a sedimentary layer of fallen leaves and branches. Layers A1 and A2 are the most superficial mineral soil layers with a notable comingling of organic matter.

IV. Conclusions

Figure 5 presents the standing stock of ^{137}Cs in each part of the plots covered respectively by a deciduous broadleaf forest and an artificial cedar forest as of September 2014.

These different types of forests commonly retain the greatest amount of ^{137}Cs in their litter layers and topsoil. The buildup inside plants is expected to be relatively small. Nonetheless, the most crucial finding of the monitoring that has been conducted so far is the fact that radioactive cesium continues to migrate actively without any stable distribution with a specific spatial alignment. The internal circulation in the ecosystem was particularly visible along nutrient cycle pathways between plants and the soil. The ^{137}Cs migration diminished year by year in the evergreen artificial forest of Japanese cedar, with the concentration in the trees' new needle leaves at the level of a few thousand Bq kg^{-1}. In the future equilibrium, the amount of absorption into the tree body is expected to reach a similar level to the amount of migration to the forest floor.

Meanwhile, a certain portion of the ^{137}Cs is believed to seep down into the mineral soil layer to be retained by clay minerals. However, internal circulation between plants and the litter and humus layers is expected to last for a long time. The availability of radioactive cesium for creatures is reduced by its adsorption and retention by clay minerals. However, it is reasonable to assume that radioactive cesium remains available for creatures as long as the internal circulation is maintained between plants and the litter and humus layers. The internal circulation mechanism and the circulated amount of radioactive cesium must be observed carefully and continuously. In addition to the monitoring that is to be continued in the medium to long term, detailed studies on the processes that take place in litter layers and on the ground surface remain important.

Acknowledgments

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Report

Progress on Off-Site Cleanup Efforts in Fukushima 2016

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Decontamination has been pursued in Hamadoori, Nakadoori, and various other parts of Fukushima Prefecture since the nuclear accident that occurred there in March 2011. Pursuant to the Act on Special Measures Concerning the Handling of Environmental Pollution by Radioactive Materials Discharged by the Nuclear Power Station Accident Associated with the Tohoku District – Off the Pacific Ocean Earthquake That Occurred on 11 March 2011 enacted in August of that year, the Ministry of the Environment (MOE) is conducting decontamination in 11 municipalities located in the evacuation zones. The efforts being led directly by the Japanese government are aimed at completing the extensive decontamination of the target municipalities by the end of FY2016, except in difficult-to-return zones. This article reports on the progress that has been made since the publication of the last commentary in spring 2014 as well as the challenges ahead.

KEYWORDS: Off-site cleanup, decontamination, radioactive pollution, Fukushima, Ministry of the Environment

I. Introduction

"Did you drink the local water and eat the local rice?" "Is decontamination really effective?" "Have you really not been affected by the radiation?" These are some of the questions that local leaders, doctors, educators, and other stakeholders often expect children from Fukushima to encounter when they grow up to become students and professionals and meet people in Sendai, Tokyo, Osaka, and other places outside Fukushima Prefecture. They believe that these children need special educational support to help them answer these questions about radiation and the situation in Fukushima. As a first step toward providing such support, this report presents information on the effectiveness of decontamination. It then provides an overview of the progress that has been made in terms of decontamination work and other cleanup efforts before discussing how to address future challenges, such as how to handle difficult-to-return zones.

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II. Effectiveness of Decontamination

Both in the immediate aftermath of the nuclear accident and during the five year that have followed, affected residents have often questioned the effectiveness of decontamination. In briefing sessions on decontamination work and other measures, they ask if the radioactive materials produced by the accident are carried back to decontaminated areas from areas that have yet to be decontaminated or other such sources via natural phenomena such as the wind and streams. This section describes dose surveys that have been conducted along with the decontamination work, discusses their effectiveness in helping to reduce the air dose, and explains how temporary storage yards are managed, which is a matter of concern for local residents.

1. Dose Surveys Conducted Along with the Decontamination Work

In decontamination target areas, the air dose is surveyed in advance with due consent from the relevant landowners. Dose measurements are also conducted immediately after decontamination work has been completed. A monitoring survey is conducted about six months to one year later. If the reduced air dose is not maintained at any of the sites, the cause is investigated. If necessary, follow-up spot decontamination work is conducted, after which the relevant sites are continuously monitored.

As of August 2016, the air dose had been measured at 990,000 sites (where approximately 620,000 were in residential areas, 120,000 were on farmland, 60,000 were in forests, and 190,000 were on roads) prior to the start of the decontamination work conducted directly by the Japanese government. In areas with a relatively high dose, the radioactivity concentration is also measured in advance of any decontamination work in consultation with the local community.

The compiled findings from monitoring surveys have facilitated the identification of land features and building structures that may attract radioactive materials after their decontamination. Particular attention is paid to examining places such as the areas under gutters, cracks in asphalt and other ground surfaces, and water channels on the slopes of hills behind houses. At present, these sites are carefully examined even during the first round of decontamination work.

2. Long-Term Monitoring Data

Survey data is available on reductions in the air dose following decontamination work. Such data has been accumulated over the long term in the air dose rate follow-up surveys conducted in the target areas for the pilot demonstration project that was conducted by the Cabinet Office from November 2011 to April 2012.

The pilot demonstration was conducted in 18 areas located mainly in evacuation zones, and follow-up surveys have been conducted in 14 areas[i]. Each target area has about 20 measurement sites. By the end of 2015, 11 rounds of follow-up surveys had been conducted. So far, the air dose has decreased at all of the 288 measurement sites, with different dose levels recorded throughout the area from the Ottozawa District in Okuma (average air dose rate before decontamination: 67 μSv/h) to the southern industrial complex in Naraha (average rate: 0.39 μSv/h). Continuous increases were not noted at any of the measurement sites. In these

[i] An additional follow-up survey was later begun in another area, resulting in the current total of 15 target areas.

14 areas, the decontamination work reduced the dose by about 60% on average, with physical decay assumed to account for 50% of this reduction.

3. Management of Temporary Storage Yards

As of August 2016, about 270 temporary storage yards located in the evacuation zones (including zones where the evacuation order has been lifted) stored about 7 million bags of soil (1 m^3 per bag) produced by the decontamination work conducted directly by the MOE. In addition, about 700,000 bags of combustible waste were carried away for treatment at temporary incineration facilities or the like.

Each temporary storage yard is developed in the following manner to ensure that the removed soil is managed safely until its subsequent transportation to interim storage facilities.

- An impermeable lining sheet is laid at the site.
- Large bags of the removed soil are piled up on top of the lining sheet.
- Bags of uncontaminated sand (about 1 m^3 per bag) are placed around and on top of the heap to provide radiation shielding.
- The entire heap of bags, including the top, is covered with a waterproof sheet or a suitable alternative.
- This arrangement reduces the radioactivity emitted from the removed soil by over 99.8%.
- The dose levels near temporary storage yards do not differ from those in the surrounding environment.
- Once a temporary storage yard has been developed, it is monitored through the following measures: regular patrols; weekly measurements of the air dose, temperature, and CO concentration; monthly measurements of the groundwater and seeping water; and quarterly mowing.

As of June 2016, about 5.5 million m^3 of the soil removed in decontamination work that was not carried out directly by the Japanese government was being managed by municipal governments at their 830 temporary storage yards and 145,000 direct storage sites in Fukushima Prefecture.

III. Aiming for the Completion of Decontamination

1. Special Decontamination Areas

In special decontamination areas where the Japanese government conducts decontamination work directly, 7 of the 11 target municipalities (i.e., Tamura, Kawauchi, Naraha, Katsurao, Kawamata, Okuma, and Futaba) completed extensive decontamination work in accordance with their decontamination plans. **Table 1** shows the progress that had been made by August 2016 in the remaining 4 municipalities. All of these municipalities plan to complete extensive decontamination work by the end of FY2016 according to their plans. For the decontamination work conducted in the special decontamination areas, a cumulative total of about 9 million workers were mobilized from July 2012 to August 2016. In November 2015, the largest number of workers employed on a single day reached around 20,000.

With reference to the 4 municipalities listed in Table 1, the evacuation order was lifted in Minamisoma, with the exception of difficult-to-return zones, in July 2016. In Iitate, the order is to be lifted in March 2017 (excluding difficult-to-return zones). The evacuation order has been lifted in 4 of the 7 municipalities (Tamura, Naraha, Kawauchi, and Katsurao) that have

Table 1 Progress made in decontamination work in special decontamination areas

	Consent from landowners (%)	Progress (%)			
		Residential areas	Farmland	Forests	Roads
Iitate	99.6	100	91	98	82
Minamisoma	95	96	38	69	39
Namie	98	87	51	96	75
Tomioka	Completed	100	99	100	99.9

completed the decontamination work (excluding difficult-to-return zones).

Municipalities that have completed the decontamination work are, as mentioned earlier, conducting follow-up monitoring to ensure that the reduced dose levels are maintained. Furthermore, they continue to discuss necessary follow-up measures while maintaining close communication with local residents.

2. Intensive Contamination Survey Areas

While the Japanese government conducts decontamination work directly in special decontamination areas, municipal governments are leading the decontamination work in municipalities classified as intensive contamination survey areas in accordance with duly developed plans. As of July 2016, decontamination work had been conducted in 36 municipalities in Fukushima Prefecture.

According to their plans, the target municipalities in Fukushima Prefecture intend to complete decontamination work and other cleanup measures in FY2016. As of July 2016, nearly 90% of the decontamination work had already been conducted in residential areas, farmland, pastureland, living environments for children, and other public facilities. The decontamination work was completed for about 50% of roads and 60% of forests in habitation zones.

IV. Treatment of Contaminated Waste

1. Direct Treatment of Contaminated Waste by the Japanese Government

Areas for the direct treatment of contaminated waste by the Japanese government were designated in 11 municipalities with an overlapping designation as special decontamination areas. As of January 2016, an estimated total of 1.165 million tons of disaster waste had been produced in these areas. By August 2016, 990,000 tons of waste from the affected sites had been consolidated in temporary storage yards, of which 150,000 tons had been treated by incineration and 380,000 tons had been recycled.

As part of ongoing efforts for evacuees to return to these areas, the clearance waste that they produce during their temporary return is also being collected and treated. In parallel, affected houses are also being demolished. As of August 2016, 3,900 houses had been demolished and removed in response to about 9,400 applications.

Plans were formulated for the construction of temporary incinerators to treat the combustible part of the disaster waste from these areas at nine sites in eight municipalities: Kawauchi, Iitate (Komiya District and Warabidaira District), Tomioka, Minamisoma, Katsurao, Namie, Naraha, and Okuma. As of October 2016, an incinerator was under construction in Okuma, an incinerator in Kawamura had completed the treatment work, and the remaining seven facilities in six municipalities were in operation with a total daily capacity of 1,600 tons. By August 2016, they had treated about 330,000 tons of waste (including 190,000 tons of decontamination waste).

2. Treatment of Designated Waste

Beyond the areas for the direct treatment of contaminated waste by the Japanese government, waste with a radioactivity level in excess of 8,000 Bq/kg is treated by the Japanese government as designated waste. As of June 2016, Fukushima Prefecture had generated a total of about 147,000 tons of designated waste, which consisted of 116,000 tons of incinerated ash, 10,000 tons of sewage sludge, and 4,000 tons of rice straw and other agricultural and forestry byproducts.

The volume of combustible waste is being reduced with respect to agricultural and forestry byproducts, sewage sludge, and the like by means of incineration and drying. So far, facilities have been developed to reduce the volume of sewage sludge in Fukushima and Koriyama and to treat agricultural and forestry waste in Samegawa (all of these operations had been completed as of July 2016). The volume reduction facility in the Warabidaira District of Iitate treats combustible designated waste from the district and neighboring municipalities. The development of a volume reduction facility is planned at the switching station in Minami-Iwaki between Kawauchi and Tamura to treat agricultural and forestry byproducts from the Aizu region as well as the central and southern parts of the prefecture.

3. Controlled Landfill Site

Designated waste from Fukushima Prefecture with a radioactivity level of no more than 100,000 Bq/kg will be disposed of at the existing controlled landfill site (formerly the Fukushima Eco-tech Clean Center) in Tomioka (transported through Naraha).

In December 2015, the town mayors of Tomioka and Naraha, along with the prefectural governor of Fukushima, endorsed the use of this facility, and the Japanese government nationalized the facility in April 2016. In June of that year, these bodies signed an agreement on safety measures to be implemented around the facility.

At the site, landfill disposal is planned for around 650,000 m^3 of waste with a radioactivity level of no more than 100,000 Bq/kg from among the waste produced in the areas for the direct treatment of contaminated waste by the Japanese government, designated waste, and household waste from Futaba. As of September 2016, the development of related facilities had begun and local coordination for waste transportation was underway.

V. Construction of Interim Storage Facilities

The construction of interim storage facilities with a combined area of roughly 16 km^2 is planned in Okuma and Futaba. These facilities will store soil removed during decontamination work in Fukushima Prefecture, waste from areas to be treated directly by the Japanese government with a radioactivity level of over 100,000 Bq/kg, and designated waste. The amount of waste to be disposed of is estimated to be between 16 and 22 million m^3 (after the incineration of combustible waste).

1. Land Acquisition

In the summer of 2011, the Japanese government requested that the prefectural government of Fukushima collaborate in the construction of interim storage facilities. Since then, various exchanges have been conducted through on-site surveys, local briefing sessions, and other activities that involve evacuees and the national, prefectural, and relevant municipal governments. As a result, the town of Okuma agreed in December 2014 to host one of these facilities. The town of Futaba followed suit in January 2015. Subsequently, negotiations were entered into with the over 2,300 landowners of the intended sites. Searches were conducted to find out the contact details for evacuated landowners in all parts of Japan. The purpose of the interim storage facilities was explained to these landowners through meetings or phone calls to obtain the necessary consent with regard to their houses and other properties as well as for the performance of surveys there. The properties were appraised by examining the stumpage, garden rocks, houses, and other facilities one by one to estimate their values. After that, the respective landowners were contacted to proceed with a land acquisition agreement after the results of the appraisals had been confirmed. As of September 2016, the contact details of about 1,600 landowners had been confirmed. These landowners own about 90% of the planned site. After their contact details had been identified, 1,400 landowners agreed to the performance of a property survey. These landowners account for about 80% of the planned site. The property survey was completed for 60% of the planned site. Some properties require extra time for reconfirmation after the property appraisals based on on-site surveys. As of September 2016, land acquisition agreements had been signed for 144 ha of land.

2. Transportation

In February and March 2015, the towns of Okuma and Futaba agreed to accept contaminated soil at their interim storage facilities, respectively. In March 2015, the transportation of waste was commenced to the planned sites for interim storage facilities. Prior to the construction of the main facilities, parts of the industrial complexes in both towns were designated as storage spaces. In FY2015, the transportation of waste from 43 municipalities in Fukushima Prefecture was conducted as a pilot demonstration to determine the state of transportation safety management and the challenges associated with transportation to and from the facilities. In total, about 45,000 m^3 of waste was transported to and from these facilities. The amount of waste to be transported is mostly determined by how much land is acquired at the planned sites by the previous year. According to the forecast, around 150,000 m^3 will be transported in FY2016 before increasing to between 300,000 and 500,000, 900,000 and 1.8 million, and then 1.6 and 4.0 million in the following FYs. In FY2020, this number is expected to rise to between 2 and 6 million m^3.

3. Facility Construction

Full-fledged construction of loading and segregation facilities, soil storage facilities, and other relevant interim storage facilities began in the autumn of 2016 when a substantial area was secured at the planned construction sites. At the planned interim storage sites, several sections of valleys that are separated by ranges of hills and covered with paddies extend toward the ocean. Initially, plans were formulated for facilities for the storage of vast amounts of soil to fill these valleys by forming something like dams. However, the land use and facility design must be flexibly adjusted to the status of land acquisition.

4. Recycling and Final Disposal

Interim storage facilities are intended for the storage and management of soil generated during the performance of decontamination work in Fukushima Prefecture in the immediate future. The Act on Japan Environmental Safety Corporation stipulates the principles for the final disposal of this soil outside of Fukushima Prefecture within 30 years of it first being stored in these facilities. Progress toward the final disposal of this soil is envisaged to comprise eight steps. More specifically, research and development into the relevant technologies as well as an exploration of the potential for volume reduction and recycling are to be conducted while keeping in mind the physical decay of radioactive materials. Recycling is pursued by segregating fine-grained soil—which tends to adsorb more radioactive materials—from large-grained soil brought into the interim storage facilities after the completion of decontamination operations. The possibility of making effective use of soil with a relatively low dose is also investigated for the development of properly managed public facilities.

VI. Future Challenges

1. Handling of Forests

Decontamination is usually conducted in forests that are located within about 20 m of residential areas, farmland, and the like while taking into consideration the impact on these areas. Reportedly, a subsistence economy has developed, particularly in the Abukuma Mountains, with a heavy reliance on forestry and the collection of edible wild plants, mushrooms, and other forest resources in other parts of Fukushima Prefecture with scattered radioactive materials. In response to calls voiced throughout the prefecture for careful attention to be paid to forests, a national agency began discussions in the beginning of 2016 on how forests should be handled. As an empirical experiment, a pilot demonstration for the restoration of community forests is planned.

2. Measures in Difficult-to-Return Zones

In special decontamination areas, decontamination work to date has been conducted in restricted residence zones and evacuation order cancellation preparation zones. Extensive decontamination work has not been conducted in difficult-to-return zones, except for at some pilot demonstration sites, the Joban Expressway, National Route 6, other expressways, cemeteries (which act as an important spiritual mooring for residents), and key reconstruction hubs in Okuma, Futaba, and Tomioka. In August 2016, the recommendations made by the ruling party with respect to measures to be taken in these zones were compiled. Accordingly, the government established a relevant policy at the end of that month.

The municipalities to be targeted in the future need to develop plans for the establishment of reconstruction hubs as well as conduct decontamination work and infrastructure development for these hubs. In addition, key roads will need to be cleaned up and improved to form an extensive network.

VII. Communication of the Risks Involved in Decontamination Work and Other Measures

The performance of decontamination work, the construction of interim storage facilities, the treatment of contaminated waste, and other such measures can be conducted thanks to the understanding and cooperation of affected residents and relevant agencies. In January 2012, the Japanese government established the Decontamination Information Plaza as a leading hub for risk communication in Fukushima City. In May 2014, the Support Center for Social Workers Engaged in Recovery from the Nuclear Disaster was opened in Iwaki City to facilitate radiation risk communication. Sometime later in July 2016, the prefectural government of Fukushima, the National Institute for Environmental Studies, and the Japan Atomic Energy Agency jointly opened the Fukushima Prefectural centre for Environmental Creation in Miharu to study environmental dynamics in the prefecture and engage in risk communication in a comprehensive manner.

Cooperation among these three facilities is vital, and their staff are now trying to coordinate and share information among themselves. They are expected to adequately respond to requests from Fukushima residents and provide them with the necessary advice.

Of these three facilities, the Decontamination Information Plaza has served as a platform for risk communication and exchanges in Fukushima since the early stages. Their activities can be outlined as follows.

- Purpose of establishment: Provision of information regarding decontamination work, radiation, etc.
- Management: Joint operation by the MOE and the prefectural government of Fukushima
- Activities
  - Dispatching of experts: Registered experts on decontamination work and radiation are dispatched to workshops as requested by the municipalities
  - Stationary exhibitions: Exhibitions and briefings are provided to facilitate greater understanding of decontamination work
  - Mobile exhibitions: Exhibitions and briefings on matters related to radiation and decontamination work are provided at events as requested by the hosting municipalities
- Achievements (February 2012 to August 2016)
  - 1,193 experts dispatched for over 47,000 participants at workshops
  - Mobile exhibitions organized at 460 venues, with over 51,000 visitors being hosted over a total period of 593 days
  - Over 22,000 people visit the Decontamination Information Plaza

VIII. Conclusions

With respect to the issue mentioned at the beginning of this report, although some children from Fukushima may be resilient enough to adequately explain the local conditions and talk about radiation, some children might be discouraged from eating local rice and drinking local water. It seems odd for host communities to ask children who have had to move away from their home prefectures to explain about Fukushima. Instead, the host communities should learn more about decontamination work and radiation so that they can offer vital support to these young new members of the community.

In Japan today, this approach is probably one way for the country to genuinely apply the lessons learned from Fukushima.

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Part II

Nuclear Safety and Regulation

Commentary

Reframing of Nuclear Safety Logic on the Basis of Resilience Engineering

Tohoku University, **Masaharu Kitamura**

Public discussion on the future of nuclear energy depends crucially on how nuclear safety is established in the wake of the Fukushima Accident and how it is explained to the public. This issue cannot be addressed by simply explaining the technical measures that need to be introduced to enhance safety. How could an accident be whitewashed by simply dismissing it as an unexpected event? Why did the concerned parties fail to immediately take heed of the warnings given before the Fukushima Accident about the likelihood of tsunamis and station blackouts? The public rejection of nuclear power will remain unchanged unless such questions are properly addressed. This commentary explains that the logical backing provided by safety based on defense in depth as applied in the nuclear sector, which had been considered inherently adequate, has been undermined due to changes to the intended targets over time and efforts to adapt to changes involving the incorporation of new findings. In future discussions of nuclear safety logic, it is vital that the nuclear industry adapt to these changes effectively. This commentary also describes the significance of resilience engineering as a guiding methodology for dealing with the relevant changes.

I. Introduction

"Continued nuclear power generation is inconceivable after the calamity brought about by the Fukushima Accident." "The resumption of nuclear power generation cannot be approved without a guarantee of no accidents." Such opposition to nuclear power generation is voiced almost every day. However, there are also voices who argue in favor of continued or expanded operation of nuclear power plants by stating, for instance, that "Nuclear power plants need to be operated to a certain degree given the circumstances of tight energy and regional power supplies in Japan" and "Resumption is acceptable now that plant safety has been enhanced by the adoption of various safety measures." These conflicting opinions can be heard among citizens, experts, and politicians if we observe media coverage.

The most important cause of these clashes is almost certainly the inadequate response to serious safety concerns. Other problems related to nuclear power include issues concerning the final disposal siting for highly radioactive waste, the stagnation of the nuclear fuel cycle,

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and the high costs involved in considering the possible effects of accidents. The biggest concern for the public is the perceived danger of nuclear power, which was reinforced by the Fukushima Accident. Kikkawa [1] rightly points out that "In the wake of the accident at the Fukushima Daiichi Nuclear Power Plant, Japan cannot operate nuclear power plants simply out of necessity. It is impossible for their operation to be resumed unless Japan faces up to the hazards involved by adopting measures to minimize such hazards while meeting energy needs."

In keeping with this view, nuclear experts should thoroughly examine and explain the reasoning for their claims about nuclear safety and the validity of such claims. Since June 2011, this journal has already presented explanations of the causes of the Fukushima Accident and discussions on measures that should be taken going forward. To the best of the author's knowledge, however, nuclear safety has not been discussed with respect to a logical system except for the contemporary opinion expressed by Morokuzu [2] in reference to the need for such a discussion. (After this commentary was submitted, the August 2012 issue of the Journal of the Atomic Energy Society of Japan published a commentary by Hiroshi Miyano et al. entitled "Prevent Recurrence of Nuclear Disaster (2): Reconstruction of Safety Logic Diagram of Nuclear System" [in Japanese]. Although the proposals made in these two commentaries differ, they share some commonalities in terms of their overall purposes.)

Regardless of who is right or wrong, the conflicting arguments mentioned earlier and any further discussion are irrelevant and pointless unless we question the logic behind the claims about nuclear safety and explanations of how nuclear safety is ensured (hereinafter referred to as "nuclear safety logic"). If the conventional nuclear safety logic is wrong, what aspects of it need modification? If it is not wrong, then why did it fail to prevent the Fukushima Accident? What types of modifications would significantly enhance safety? Further consideration must be given to these kinds of questions. Once answers have been obtained, it will also be necessary to consider how they can be clearly explained to the public. Future nuclear policies should no longer be discussed and decided in a broad sense along conventional lines involving the exclusive participation of nuclear experts (often sarcastically referred to as the "nuclear village"). Even before the Fukushima Accident, a wide range of people had advocated the adoption of trans-science, which calls for the involvement of citizens in addressing problems that arise between technologies and our society rather than just leaving this task to a group of experts [3, 4]. This participatory policymaking took on even greater importance after the accident. Given these circumstances, it goes without saying that explanations of nuclear safety are important and necessary.

As someone involved in the nuclear sector, the author felt at loss about how to react to the inconvenience and pain experienced by members of the local community in the wake of the serious accident that occurred in Fukushima. All that came to mind were words of apology and remorse. However, regardless of the type of scenario that Japan decides to choose, a reexamination of the nuclear safety logic and an adequate explanation of this to the public are tasks that cannot be shirked. Nuclear experts have a duty to make a sincere effort to learn lessons from the Fukushima Accident. With this in mind, the discussion proceeds as follows.

II. Nuclear Safety Logic

We need to start by considering how the questions raised in the previous chapter should be answered. What efforts had the nuclear sector stakeholders, who eventually failed to prevent the Fukushima Accident, actually made?

With respect to this question, it should be noted that the existing Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors attempts to prevent accidents through just three approaches: (1) prevention of abnormal operation; (2) prevention of escalation; and (3) mitigation of impact. The majority of nuclear experts would share the view that the five levels of defense in depth advocated by the International Atomic Energy Agency (IAEA) additionally try to implement measures for dealing with severe accidents and emergency preparedness [5)]. A wide range of comments highlight the limitations of the three approaches mentioned above.

However, the nuclear safety logic was not necessarily created in this way from the beginning. Nuclear safety experts at least knew that the nuclear safety logic was created to provide defense in depth with many more levels of protection [6)]. The quoted document was written by a former member and chair of the Nuclear Safety Commission. This defense in depth adopts a total of seven levels of defense: (1) siting; (2) suppression of abnormal events; (3) early detection and response to abnormal events; (4) mitigation of impact; (5) accident management; (6) isolation to minimize any interaction between the facility and society as a whole; and (7) emergency preparedness. Leaving aside the details, it is clear that Japanese guidelines at least ensure a level of safety that is comparable to that provided by the international guidelines advocated by the IAEA. Simply put, the nuclear safety logic that was previously known in Japan already considered a broader range of aspects than just the prevention of abnormal operation, the prevention of escalation, and the mitigation of impact.

Rather than asking why nuclear regulations and plant operations in Japan have been backed by defective safety logic, the question we should be asking is why the original nuclear safety logic with seven levels of defense has atrophied and degenerated into one with just three levels of defense in practice. If the only known logic was, in principle, defective and consequently compromised safety, modifications to this logic could enhance safety. However, the truth is that the atrophied and degenerated version of the original logic had already been adopted. Given this, it is necessary to identify and eliminate the causes of this change for the worse. The top priority is to implement measures to prevent any failure to detect signs of deterioration or take the necessary actions.

A commonly encountered explanation for this deterioration of safety is the allegedly evil nature of stakeholders in the nuclear industry based on the criticism that “Blinded by their own interests, members of the nuclear village have neglected safety.” This may not be entirely off the mark, but our intellectual efforts should not stop there. It is human nature to simplify an issue to minimize the cognitive burden associated with handling it. Furthermore, people tend to persist with their view once they have made a judgment. J. Reason, an internationally respected authority on the human and organizational impact on safety, warns of this tendency, which he describes as the “principle of minimum effort” or the “principle of supervisory convenience [7)].” An obsession with assuming that an accident was caused by someone’s mistake or negligence is also identified as a problem in the field of human factor safety engineering. This issue requires much deeper consideration.

III. Factors Behind the Undermined Nuclear Safety Logic

As stated in the previous chapter, investigating the causes of an accident based on a simplified assumption often ends up in a partial understanding of the reality of the situation. Nuclear experts are widely criticized for having stopped thinking in relation to their assumptions concerning earthquakes and tsunamis. The author also shared such a view [8)], but only in the limited context required to preclude any excuses by engineers that they did not anticipate certain events. In terms of this commentary, the essential task is to develop a big picture of the way in which the nuclear safety logic atrophied and degenerated.

A standardized criticism of nuclear experts is often encountered. The press tends to adhere to a narrative in which safety was undermined when members of the nuclear village fell into a trap of their own making by believing their own myth of safety. In Chapter 9 of its report, the Independent Investigation Commission on the Fukushima Daiichi Nuclear Accident expressed its own view on the social background to the myth of safety. In a general sense, this myth of safety conjures an image of complacent groups of people who blindly believe in nuclear safety and neglect to take adequate safety measures. However, such a perception only presents one side of the story. This view is unerringly criticized by a commentary [9)] published in this journal.

"After the Fukushima Accident, some experts criticized the nuclear industry by saying that it had been beguiling citizens with the myth of safety. However, such comments do not necessarily hold water. For instance, the Kansai Electric Power Company substantially corrected the statement published in its public relations journal claiming that 'accidents never happen' when an ECCS was prompted to operate during the accident at its Mihama Nuclear Power Plant in 1991. The 2000 issue of the White Papers on Nuclear Safety published by the Nuclear Safety Commission clearly stated that they would break away from the myth of safety."

Based on his practical experience, the author did not believe that experts simply assumed that no accidents would take place. In fact, the author felt uncomfortable with the various clichés that were propagated whenever nuclear power plants experienced trouble, such as that the myth of safety was dead. It is wrong to assume that blind faith in the myth of safety meant that we could not prevent the accident. Completely different mechanisms should be considered as possible causes.

Let us instead focus on the following statement in a report by the Independent Investigation Commission: "During the study, senior government officials responsible for nuclear safety and the former management of the Tokyo Electric Power Company made the unanimous statement that although they were aware that the safety measures were inadequate, they believed that nothing would change even if they went against the prevailing opinion" (p. 7). We need to give careful consideration to this statement suggesting that many stakeholders remained silent even though they were all aware of the problem.

The author did not foresee the hazard posed by the last major tsunami. Feeling ashamed of his incompetence, he presented some possible measures aimed at preventing a repeat of this failure to predict important events [8)]. As long as their views are sincere, we need to introduce other measures to keep people from remaining quiet about problems despite being aware of them. The paper published by Kinoshita [9)] classifies unanticipated events into five categories, and the author employs a similar classification for this commentary as shown in **Table 1**. According to this classification, none of the nuclear accidents and problems experienced in the past could be considered unanticipated in a strict sense. Arguably, proper measures could have been taken if enough attention had been paid to errors made by the evaluators.

The author is not claiming that all events can be anticipated. In principle, the possibility of unanticipated events cannot be denied, but unanticipated events experienced in the past were actually excluded from predictive efforts. The number of unanticipated events could actually be considerably reduced, thereby helping to enhance safety. To do this, we need to avoid the imprudent (or intentional) exclusion of any event from predictive efforts. Instead, we should always ask if anything could be done if the event were to occur and take measures accordingly if it does take place.

Table 1 Classification of possible unanticipated events and judgment errors by evaluators

Event category	Event characteristics	Factors related to judgmental errors by evaluators	Typical example
(1) Extremely unlikely event	The event is objectively unlikely.	The probability can be deemed virtually nil. However, it is not acceptable for it to be omitted from an impact assessment.	Meteorite impact
(2) Simultaneous occurrence of multiple failures	The combination of events is unlikely if considered as an independent event.	This is unacceptable without consideration being given to common factors that may cause damage to multiple pieces of equipment and the loss of multiple functions.	Simultaneous functional loss of redundant power supplies and multiple cooling systems like the one that led to the Fukushima accident
(3) Controversy among experts (scientific community)	The majority deems the event unlikely, while a minority thinks it is likely.	A decision being taken by the majority without examining the reasoning of the minority.	Judgment error concerning the presence of active faults and their possible interactions
(4) Earthquakes, tsunamis, and other natural disasters	The probability is not negligible, but the timing is highly uncertain.	An incorrect interpretation of uncertain timing meaning that it is not likely in the near future.	Inadequate consideration of a major tsunami that takes place at an interval of XX years (XX years since the last one)
(5) Events that also require non-nuclear expertise	The probability is not negligible, but there is no precedent for such an event.	The event scenario is overlooked due to inadequate expertise and a failure to recognize the relevant information.	Damaged thermometer casing at the Monju reactor
(6) Human and mechanical interactions	The event scenario is complicated by human and mechanical interactions.	Unduly inoperative equipment and difficulty in reading instruments.	Three Mile Island accident
(7) Organizational factors	Multiple factors associated with undermining the safety culture of the overall organization	A scenario of inadequacy that is usually unlikely in a normal organization is overlooked.	Chernobyl accident, JCO accident

Safety is clearly undermined if an increasing number of events are excluded from predictive efforts. Five or seven levels of protection in defense in depth were reduced to just three levels in practice, thereby leading to an atrophied nuclear safety logic. In addition to the neglect caused by the errors mentioned in Table 1, many events obviously tend to be excluded from predictive efforts due to advances in science and new findings gained along the way. New findings on earthquakes and tsunamis have been continuously acquired ever since safety reviews were first conducted during the construction of the Fukushima Daiichi Nuclear Power Plant and other nuclear power plants. It is widely known that the risks of tsunamis and station blackouts were identified well in advance (e.g., in reports published by the Independent Investigation Commission and the National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission). These new findings and identified issues could have served as important warnings.

Put another way, the fundamental factor behind the accident was inadequate sensitivity to alerts among utilities, regulators, and their organizations. As a reason for this, a number of people have identified an aversion to the increased costs associated with any changes. The report by the Independent Investigation Commission mentioned earlier also states the following: “The aforementioned former managing director confided that directors were evaluated based on their performance in relation to reducing costs in line with the slogan set by former President Araki to become an ordinary company, which undermined safety” (p. 319). Combined with the earlier quote, the scenario indicating that concerns over increased costs were the main reason seems convincing. However, even if this remark was genuine, the investigation into the accident should, according to widely known practices, go beyond this convincing scenario to examine the secondary story behind it [10]. Would these concerns over rising costs keep people from speaking up if a highly realistic tsunami alert was issued?

In practice, such an alert for a likely tsunami may have been excluded from the predictive efforts based on its classification in Table 1 under "(4) Earthquakes, tsunamis, and other natural disasters" and the assumed "(3) Controversy among experts (scientific community)." Most probably, the risk of undermined safety may in reality have been overlooked in light of the "(2) Simultaneous occurrence of multiple failures." It is highly likely that, behind the scenes, there was a vague resistance to any changes. The source of this resistance can be traced back to the principle of minimum effort, as quoted in Chapter II. It is quite conceivable that people dealing with an enormous nuclear power plant tend to feel that they do not need to respond to every single alert without sufficient evidence or that safety can be maintained by the robust construction of the plant without any improvements or changes. In other words, the root cause is the static assumption that, once a certain degree of safety has been achieved with a target model, safety can be maintained by proper maintenance and the prevention of human error.

Precisely for that reason, the prevention of another accident like the one in Fukushima and the enhancement of safety at nuclear power facilities should be fundamentally guided by efforts to enhance sensitivity to alerts, avoid exclusions from predictive efforts, and overcome resistance to changes. However, we cannot expect such effects to be made if these basic guidelines are simply treated as a philosophy. A tangible methodology is needed to translate the guidelines into realistic and functional policies within the organization and to develop the necessary system. The resilience engineering described in the next chapter is expected to play an important role as the required methodology.

IV. Ideal Nuclear Safety Logic and Resilience Engineering

Based on the above discussion, it is reasonable to ascribe the Fukushima Accident to the mindset of nuclear experts who neglected the need for changes and excluded various events from predictive efforts. Resilience engineering lies diametrically opposite such a mindset [11, 12]. This methodology prompts us to consider safety based on the basic understanding that any system and environment undergoes changes and that hazards can affect us at any time. For illustrative purposes, it can be compared to the guidelines followed by the captain of a sailing boat navigating a sea full of islands and treacherous reefs. Leaving a more detailed explanation to another paper [13], this commentary only presents an overview of resilience engineering.

Resilience engineering is a methodology that has been gradually developed by western researchers on safety as well as researchers and practitioners of human factors. Conventional studies on safety and human factors assumed that the nature of target systems remained constant over time. Human operators and pilots were regarded as error factors. Earlier studies sought to eliminate such errors, but the limitations of this approach gradually became apparent, and human factors were also recognized as potential sources of success. This awareness prompted the rapid development of resilience engineering from around 2004 [11, 12].

The basic stance of resilience engineering can be summarized as follows.

A) Systems (nuclear power plants and operating organizations in relation to this commentary) and environments (natural and social) experience constantly dynamic changes. They may not be considered as unchanged.
B) System operators must always have a constant sense of unease and adapt to changes as necessary.
C) A response should be taken as soon as possible and appropriate in the event of any

changes or external disturbances that could affect the systems.

D) System operations should be maintained by avoiding a critical catastrophe even if the expected function cannot be maintained due to a major change or an external disturbance. In such an event, flexible operations should be pursued without insisting on the initial goals.

E) System operators should be regarded not only as potential sources of errors, but also as potential sources of outstanding success.

This framework strikes a contrast with the conventional approach to safety, in which static and constant conditions are considered desirable. Such a framework is clearly more practical considering the degree of difficulty involved in dealing with the way the Fukushima Accident unfolded. The following measures need to be implemented for all systems to satisfy the requirements.

(a) Four functions must be ensured: (1) response to ascertain what needs to be done in the given situation; (2) conscious monitoring of matters that require attention; (3) anticipation of possible hazards; and (4) learning lessons from events that have been experienced previously.

(b) The required resources must be deployed to support these functions (e.g., personnel, equipment and devices, drawings, procedural manuals, other reference materials, and funds).

(c) The allocation of resources within the system must be dynamically optimized according to the prevailing conditions.

(d) Ideally, these functions (especially monitoring and anticipation) should be applied in a proactive manner, not a reactive manner.

(e) Importantly, lessons should be learned not only from failures, but also from successes and best practices.

Bearing in mind what happened during the Fukushima Accident, it should be clear that these specific measures are considerably more rational than those required by conventional nuclear safety logic. In addition to the four key functions described in (a) above, complementary requirements are provided in (b) through (d). These functions and requirements are flexibly applied according to the situation without any predefined order. **Figure 1** provides a schematic illustration of resilience engineering.

For example, the following strategy could be adopted in the aftermath of a major earthquake.

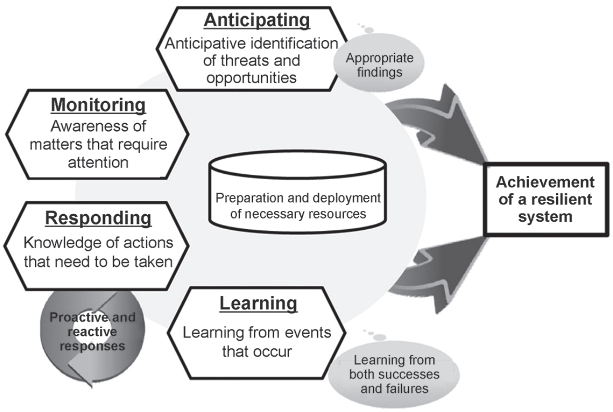

Figure 1 Four key functions of resilience engineering and complementary requirements

(1) Respond to immediate needs by mobilizing the necessary resources.
(2) This response should be combined with careful monitoring to alert those in charge of the response.
(3) Make arrangements for the necessary resources in advance.
(4) Change the strategy as necessary after implementing response measures prepared in advance of the emergence of a threat.
(5) Anticipate further likely threats and notify the person in charge of management of the necessary measures.
(6) Once the emergency has been dealt with, compile the findings and provide input data to enable lessons to be learnt from the emergency.

During routine operations without any external disturbances, the following strategy could be taken.

(1) Always utilize the anticipation function to analyze the probability of systemic or environmental changes as well as any external warning data.
(2) When doing this, duly refer to the learning data gained from past events.
(3) If a threat is anticipated, enable the monitoring function and check the necessary resources for implementing a response. Modify the deployment of resources as necessary.
(4) If the threat does not materialize, return to anticipation mode and learn from the anticipation results.

In this way, system operations based on resilience engineering ensure that one or all key functions are always activated. This practice precludes the exclusion of certain events from predictive efforts as well as reduced sensitivity to alerts. Therefore, it can be claimed in a structured manner that systems (nuclear power plants in this context) can be made much safer. Resilience engineering clearly offers a more rational approach to achieving safety as it recognizes constant changes in systems and environments.

V. Dialogue with Citizens as a Prerequisite

Let us suppose that safety can be enhanced in the manner described in the previous chapter. However, nuclear power generation cannot be continued in today's society without first gaining public support by providing citizens with an explanation of the facts. In the past, safety was based on the atrophied nuclear safety logic through the provision of three levels of protection. A typical response to any criticism tended to be as follows: "The assumption of such an extreme event (a massive earthquake or damage to a primary containment vessel) is unrealistic. Please be assured that it will never happen." This kind of explanation has obviously lost its validity since the Fukushima Accident.

Even before the Fukushima Accident, though, we should have taken heed of the five levels of protection advocated by the IAEA or the seven levels of protection mentioned earlier. An appropriate explanation would have been something like the following: "We believe that such an event will not take place. However, we would not let any such event escalate into an accident. We are prepared to deal with such an event." Going even further, an explanation should have been provided with respect to the multiple levels of protection. Let us take the following question as an example: "What should be done if this event were to escalate into an accident for some reason?" Possible responses include "The necessary level of water would still be ensured for the core even in those circumstances" and "A hydrogen explosion can be avoided even if the water level cannot be ensured." In fact, such preparedness forms the essence of defense in depth and resilience engineering. Blind adherence to conventional explanations is not acceptable. To move in the right direction, we should seek public understanding by adding explanations such as the following: "We are always prepared and trained to respond swiftly to any abnormal events" and "We will adequately respond to all alerts."

On a related note, let us consider how to respond to a criticism that is often heard with respect to the controversy over whether to resume the operation of nuclear power plants: "Resumption is unacceptable when not even the tide embankments and quakeproof administrative buildings have been constructed yet." If this sort of claim is accepted, we will face opposition to every attempt to introduce new safety measures, with people saying: "The fact that the new measures have not been carried out yet makes the existing system dangerous and thus unacceptable." Naturally, discussions concerning safety cannot be conducted in a binary manner where matters are simply labeled as either black or white. An explanation of the nuclear safety logic through defense in depth requires much greater efforts than the conventional approach of explaining matters away by saying: "Such an extreme event will never happen." Nonetheless, experts have a duty to continue making the efforts necessary to consistently explain the nuclear safety logic that combines defense in depth with flexible responses to changes with the aim of reducing the likelihood of unanticipated events. Explanations of safety based on resilience engineering offer a significant leap forward in terms of fulfilling our professional duties.

VI. Conclusions

This commentary sorted out various issues related to reframing nuclear safety logic and the significance of adopting the perspective of resilience engineering. Regardless of the outcome of discussions over the phasing out of nuclear energy, these issues need to be sorted out and discussions need to be carried out in a logical manner. This commentary points out that the conventional logic used in support of nuclear energy was not mistaken in essence, but it demonstrated that the failure to prevent the Fukushima Accident resulted from tunnel vision and the exclusion of certain events from predictive efforts while the logic was applied to actual nuclear power plants. As a possible solution to this problem, the methodology of resilience engineering was described as a framework for measures designed to enhance safety. Nuclear experts should share a common understanding of the significance of studies on safety based on resilience engineering and the specific measures that are necessary. They are also expected to communicate such information to the wider society.

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Commentary

From Ideas and Concepts to Practice
−Improving Effectiveness in Implementing Recommendations−

TeMS Co., Ltd., **Masaharu Kitamura**

Investigation reports on the Fukushima Accident form just one part of the numerous criticisms and recommendations that have been publicly announced with respect to reforming the way nuclear energy is harnessed. Nevertheless, a major problem has been encountered when attempts have been made to address these criticisms and put recommendations into practice. In essence, this problem is due to an absence of clearly defined measures for translating principles into practice. No matter how brilliant a recommendation may be, it will not work in practice if it is infeasible or there is no clear pathway for putting it into practice. This commentary seeks to address this problem by discussing findings related to subjects such as human factors, organizational management theory, resilience engineering, and science-technology-society (STS) studies.

I. Introduction

"Something important seems to be missing." This sense of discomfort persisted whenever the author heard opinions related to nuclear issues after the Fukushima Accident and read reports from the government, the private sector, and the Diet's investigation commission (NAIIC)[1-3]. Certainly, it is only natural for stakeholders in the nuclear sector to be subjected to harsh criticism and urged to make fundamental changes to nuclear technologies while taking heed of recommendations. Moreover, they have a duty to address criticisms and to translate recommendations into tangible actions. However, an awareness of this was not enough to dispel the nagging sense of discomfort felt by the author.

To determine why something important seems to be missing, the author examined findings related to subjects such as human factors, organizational management theory, resilience engineering, and science-technology-society (STS) studies. This examination identified some of the causes of this sense of discomfort along with possible measures for addressing these causes. Taking the opportunity provided by the current momentum for improved nuclear safety and the ongoing development of the necessary regulatory framework, this commentary presents observations made from various perspectives that have not been explicitly taken into account to date.

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II. Overview of the Author's Sense of Discomfort

Taken as a whole, the sense of discomfort felt by the author is caused by the existence of an unclear pathway for addressing comments from investigation reports and putting recommendations into practice. In other words, it is unclear how principles should be translated into practice. The accident investigation reports only presented principles and guidelines, leaving people on the frontline to deal with the practical problems. This approach is actually the prevailing reporting style in Japan. To be fair, this approach is reasonable provided that it is meant to encourage practical on-site initiatives based on set principles and avoiding micromanagement. However, those in charge may become confused unless the principles and guidelines have proven feasible and practical measures are presented in a convincing manner. Both nuclear sector stakeholders and society as a whole may lose out in terms of time invested in exploring measures for putting recommendations into practice if they turn out to be unfeasible. The author has examined the factors behind this unclear linkage between principles and practice. The following sections examine the various factors behind the existing sense of discomfort with reference to specific examples.

1. Rebuilding a Safety Culture

The government's investigation committee on the accident that occurred at the Fukushima Nuclear Power Plants has strongly urged utilities, regulatory authorities, concerned bodies, council members, and other stakeholders in the nuclear sector to try to rebuild a safety culture (government, p. 429) [a]. The International Atomic Energy Agency (IAEA) has defined a safety culture as "the assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, protection and safety issues receive the attention warranted by their significance." Accordingly, many nuclear organizations establish basic policies, codes of conduct, and the like. Slogans and guidelines such as "safety first," "questioning attitude," and a "reporting culture" are stressed on the sites of nuclear projects. However, a certain amount of ingenuity must be exercised to translate these principles into tangible actions. In practice, it is not easy to implement measures translated from principles as the process involved requires many tradeoffs.

No recommendations have not been issued to tangibly assess the level of the safety culture (to facilitate the rebuilding process). The accident investigation report published by the government sets out specific check items (government, p. 427) for evaluating the level of the safety culture while referring to the opinion of J. Reason as a leading authority on organizational safety. However, it is still abstract and unclear how some of these items should be applied in practice. The following are a few examples of these items.

- Can management make an unwavering decision on safety?
- Is a policy in place to independently ensure safety regardless of financial standing or business performance?
- Are any imperfect conditions or risks subject to lax judgments or are they glossed over?

It is unclear what the report meant by an "unwavering" decision or to "independently ensure safety." It is also unclear what they meant by "lax" judgments in response to imperfect conditions or risks. At present, we know that the Tokyo Electric Power Company (TEPCO) misjudged the risk of major tsunamis. With the benefit of hindsight, the decision that was

[a] This commentary cites extensively from reports published by the government, the private sector, and the Diet's investigation commission. To save space for the references, the sources of information from these three types of reports have been simplified by recording them as "(government, p. xxx)" or "(Diet, p. yyy)," for example.

taken was by no means “unwavering” and the judgment was “lax.” However, the real problem concerns what can be expected in the future. Many individuals and organizations will issue warnings and share opinions on nuclear safety. Therefore, it is necessary to determine what types of responses satisfy the recommendation items as measures in order to facilitate concrete decision-making.

2. Safety First and Litigation Risks

Litigation risks are mentioned both in terms of the safety culture and in the context of a criticism that the regulations are captured by utilities (Diet, p. 520 and p. 525). More specifically, the risks postulated by TEPCO included measures prompted by severe accidents, shutdowns of existing reactors, and weak positions in terms of litigation (Diet, p. 525). The regulatory authorities are criticized for working in coalition with TEPCO to reduce litigation risks, which contradicts their intended mission (Diet, p. 489). Meanwhile, some have pointed out that litigation related to the safety of the Ikata Nuclear Power Plant led to a need to prepare evidence proving the safety of each nuclear power plant and that the resultant safety regulations are deprived of a mechanism for ensuring the overall safety of nuclear power plants (private sector, p. 300). In practice, this comment implies that utilities face much higher litigation risks. The author does not criticize parties who bring cases to courts. However, the recommendation that, for fear of litigation risks, a safety culture should be strongly built without a tunnel vision rings hollow. In reality, the nuclear power utilities and regulatory authorities are at a loss about what measures to be done in practice. This issue is directly related to the feasibility of the recommendations.

3. Issue Related to the Disposal of High Level Radioactive Waste

The issue is not explicitly mentioned in the accident investigation reports, but it is known to have an intrinsic importance to the discussion of nuclear issues. In discussions related to nuclear energy, the author and his colleagues have often seen the lack of support for nuclear power justified by claims that the issue of disposal remains unresolved (or indecisiveness concerning nuclear power caused by confusion over the issue). In other words, the resolution of the disposal issue is a prerequisite for formulating a nuclear policy. Meanwhile, the Atomic Energy Commission of Japan asked the Science Council of Japan to discuss this issue. The council responded [4)] by saying that it is vital to present an overriding principle for the nuclear policy to gain broad public understanding. Here, the resolution of the disposal issue is premised on formulating the nuclear policy. These two issues form a circular relationship in which a failure to resolve one issue makes it impossible to address the other. Finding a solution to such a relationship is extremely difficult. The council went on to recommend that a venue be established to allow an epistemic community of autonomous scientists to engage in specialized discussions and that such discussions be coordinated by an impartial third party. These recommendations seem reasonable in principle, but it is unclear how they should be put into practice.

4. Lessons Learned from the TMI Accident

More than one investigation report discusses the Fukushima Accident in relation to the Three Mile Island (TMI) Accident. A report by the NAIIC devoted many pages to explaining the reform of US regulatory bodies after the TMI Accident. It points out that “the Japanese regulatory system lagged behind that of the United States and France after the reform ... which led to the failure to prevent the Fukushima Accident and its escalation" (Diet, p. 573). This is a valid comment, but it should be noted that considerable technical measures were implemented in Japan following the TMI Accident. Without going into too much detail, it is safe to say that Japan was relatively quick to introduce the safety parameter display systems (SPDSs) and alarm filters required to classify alerts by their degree of importance. Looked at differently, recommendations concerning hard measures can be easily applied in Japan because of clarity in terms of the way they should be implemented. In contrast, recommendations regarding regulations, safety management, and other soft measures arguably tend to be applied more slowly due to a lack of clarity in terms of the way they should be implemented. Recommendations that rely on principles may have been delayed for this reason.

A careful look at the report [5)] published by the President's Commission on the accident at Three Mile Island demonstrates that measures comparable to the cultivation of safety culture, which would finally attract global attention only after the Chernobyl Accident, had already been discussed extensively.

The following extracts are particularly relevant to safety culture.

- The TMI Accident could most likely have been prevented had there been a sincere response to the numerous warnings that had already been issued. (p. 29)
- The agency should be directed to employ a broader definition of matters relating to safety that considers thoroughly the full range of safety matters. (p. 63)
- The Commission recognizes that merely meeting the requirements of a government regulation does not guarantee safety. (p. 68)

This means that the nuclear industry in Japan and abroad had already been advised of a concept tantamount to safety culture and that there was no reason why the world had to wait until the shock caused by the Chernobyl Accident before action was taken. This fact clearly highlights the importance of translating principles into practice.

III. Narrowing Down the Factors Involved in the Case Studies

The case studies presented in the previous chapter demonstrate the difficulty involved in making criticisms and recommendations feasible and providing substance to them. The same problem can be commonly observed with respect to many other criticisms and recommendations. Some factors are unique to certain issues, but case studies can usually be narrowed down to a relatively few common factors.

1. Common Factors

One of these common factors is the difficulty involved in implementing safety measures. This challenge is directly associated with not only safety culture, but also litigation risks and the lessons learned from the TMI Accident. Needless to say, safety assurance must be considered in terms of both the prevention of accidents and their escalation in normal operation and the performance of an emergency response to any accidents. One other type of issue is that the disposal of high level radioactive waste also presents a core challenge in relation to the difficulty involved in ensuring the long-term safety of radioactive waste buried underground. In this respect, many criticisms and recommendations are related to the technical challenges associated with ensuring safety.

In today's society, it is no longer possible for nuclear experts to make a decision on their own as to whether nuclear solutions can be introduced in society even if engineers have determined that such solutions are safe. The conventional approach in which a group of experts explain their decisions to regulatory bodies, municipalities, local residents, and the general public is no longer a viable means of gaining widespread public support for the level of safety that has been achieved. The inevitable advent of a "republic of trans-science" [6] that involves a diverse group of non-experts has already been clearly pointed out with respect to resolving the friction between technologies and society. Investigation reports and the like on the Fukushima Accident reflect these findings to some extent. However, the author has not yet observed any discussions that delve deeper and recommend how a diverse group of non-experts can be involved in practical measures to address this issue.

Moreover, issues related to litigation risks and the disposal of high level radioactive waste must be considered with respect to environmental ethics, intergenerational ethics, administrative adequacy, and many other issues, as well as safety issue. Naturally, these issues must also be resolved in collaboration with not only nuclear experts, but also a diverse group of experts from other fields and various stakeholders. Given this, implementation of safety and collaborating with people who are not themselves nuclear specialists emerge as two important common factors. These factors are discussed in greater detail below.

2. Factors Concerning Safety

First, we need to recognize that too many discussions and proposals are made without actually providing a clear definition of safety. As has already been mentioned, safety is a concept that should not be defined in a manipulative manner and cannot be defined based on evidence [7]. This extremely important implication must be understood. Defining safety as being equivalent to the absence of unacceptable risks is nothing but a paraphrase that is essentially difficult to prove. Therefore, discussions on safety must be conducted by clarifying an operative definition of safety (or by clarifying measures for implementing safety). Unfortunately, the concept of safety is not defined when people discuss safety culture or engage in disputes over accountability for safety in litigations. This leads to confusion in relation to conflicting perspectives on safety. Future discussions should at least be based on a clearer definition of safety. The seemingly obvious basic concept of safety is evolving at the frontline of research on safety. Measures to implement safety are transforming considerably to keep pace with this evolution. To avoid any digression, the author leaves detailed explanations of these trends to the reference materials [8, 9]. However, necessary explanations will be provided later in relation to the commentary. References to new findings in relation to safety may help us to move closer to a shared perspective and ease conflict arising from firmly held opinions.

3. Factors Concerning the Collaboration with Non-Nuclear Experts

Even if investigations focus on the causes of the Fukushima Accident and ways to prevent a recurrence, a vast range of issues must be addressed. Such issues include organizational management, desirable regulations, and the involvement of local municipalities and citizens. A great deal of knowledge has been accumulated in terms of the theory and practice of various disciplines, including organizational management, social relations management, the perception and communication of nuclear risks, and regulatory science. Realistically, it is difficult for utilities and regulatory bodies to undergo training from specialists in their respective disciplines before applying the accumulated theoretical and practical knowledge in practice (as they should). Utilities and regulatory bodies usually end up facing practical issues after skimming through introductory guides that happen to be available or participating in training sessions for beginners at most.

There is considerable demand for measures to resolve issues related to the relationship between nuclear energy and society in broad terms, including the dismantling of the collusive "nuclear village," the provision of transparent explanations to society, and the promotion of greater citizen participation. Nevertheless, it is difficult for nuclear experts to independently define the extent to which certain measures would satisfactorily address recommendations and how the difficulties involved in implementing these measures should be overcome. Putting such measures into practice is another problem. It is only natural for experts in the humanities and social sciences [6] to be encouraged to play active roles in the resolution of problems related to the relationship between nuclear energy and society.

Any such solutions would require us to build a platform for interdisciplinary collaboration and take measures to ensure its effectiveness. The necessary practice of intercultural communication [10] is itself a difficult task. Consequently, issues related to nuclear power are too difficult for nuclear experts to address on their own, so collaboration with experts in the humanities and social sciences is necessary. The additional difficulty involved in achieving such collaboration compounds the challenge. Stakeholders in the nuclear sector must be prepared to deal with this twofold challenge.

IV. Measures Implemented in Response to Factors

1. Redefining Safety

As mentioned above, discussions concerning safety are intrinsically difficult. Measures to address or mitigate this difficulty have been explored with reference to the progress made in recent research on safety.

(1) Transition from Safety-I to Safety-II

Safety-I is based on the conventional view of safety. Widely known definitions include a "peaceful condition without any hazards" (*Kojien* (Japanese dictionary)) and the "absence of unacceptable risks" (IAEA, etc.). However, such definitions all assume a static state without any undesirable conditions. In contrast, Safety-II is considered important among researchers who advocate the concept of safety with an emphasis on resilience. It is defined as the "continuation of system operations while avoiding any catastrophic conditions [8]." In other words, Safety-II represents a dynamic and proactive concept that takes into consideration the necessary responses to disturbances, failures, and other such problems. Under the definition of Safety-II, accident prevention and damage minimization are the most important and necessary conditions for continuing operations. However, Safety-II does not set static safety as the ultimate goal, so it avoids ideological obsession. Instead, it considers the conditions that are desirable both during normal operations and in the event of accident. This definition is also consistent with the idea of defense in depth. The concept of Safety-II will help to ease tensions arising from conflicting ideas considerably in the pursuit of safety.

(2) Ideas behind defense in depth and Safety-II

Defense in depth is widely known to be based on the assumption that the preceding level of protection fails. The IAEA defines the five levels of defense in depth as follows: (1) prevention of abnormal operation and failures; (2) control of abnormal operation and detection of failures; (3) control of accidents within the design basis; (4) control of severe plant conditions, including prevention of accident progression and mitigation of the consequences of severe accidents; and (5) mitigation of radiological consequences of significant releases of radioactive materials. Some argue that a higher level of protection is not necessary if each level can perform its role perfectly. Certainly, it is desirable for each level to be able to ensure sufficient safety by itself. However, based on the primary idea of defense in depth, it is sensible to prepare higher levels of protection because no mechanical system or human operator is perfect.

Levels 4 and 5 are taken into consideration based on the assumption that the levels of defense stipulated in Levels 1 through 3 could be breached, even if the degree of probability is low. Before the Fukushima Accident, it was popularly reasoned that an event based on many extreme assumptions need not be considered (as the event would never take place), but that line of reasoning has been discredited. Instead, a more realistic and logical approach based on Safety-II would be as follows. Most failures and disturbances can be dealt with by Levels 1 through 3. Beyond that, Level 4 can protect local residents from any events that may overwhelm the levels of defense provided up to Level 3. Furthermore, even if the protection afforded by Level 4 fails due to a rare event, the disaster management plan in place will secure sufficient time for the evacuation of residents while also avoiding the type of chaos experienced during the Fukushima accident.

Nuclear safety experts have known about the concept of defense in depth since long before Safety-II gained recognition as an important philosophy. However, this concept could not be explained well due to inconsistencies in the understanding of safety. One investigation report explains in detail how it complicated the explanation of acceptable risk levels and severe accidents (government, p. 311 and p. 321). Safety-II will serve as a mediating concept that allows nuclear experts and citizens to gain a shared understanding of defense in depth while avoiding any discrepancies. Unfortunately, public trust in nuclear experts has already been damaged, so it is not viable for these experts alone to share the same understanding of the concept with the public. A more desirable approach would be to ask non-nuclear experts who specialize in safety to serve as intermediaries.

An important suggestion should be noted in relation to the argument that "appropriate safety and disaster control measures must be prepared for accidents and disasters that result in extensive damage regardless of their probabilities" (government, p. 413). Preparing artificial structures against any events "regardless of their probabilities" seems an almost impossible requirement. However, one must give careful thought to the interpretation of the modifying word "appropriate." It should also be noted that this requirement is only possible if Safety-II is adopted as the basic guideline.

2. Suggestions in Relation to Interdisciplinary Collaboration

Citizen participation is being explored on many fronts in relation to political decision-making involving nuclear technologies. National debate has already been attempted thanks to the efforts made by experts in the humanities and social sciences. Nevertheless, many issues remain to be resolved in terms of involving citizens in decision-making, which would certainly be a desirable development. In addition to directly importing methods that have been cultivated abroad, we should also explore measures that fit the reality in Japan. We are keenly aware that the Fukushima Accident stems in part from the blind introduction of nuclear power facilities developed in the United States. Despite the intention to strengthen citizen participation, the same mistake might be repeated even with proven overseas methods if they are adopted in Japan as is.

As the NAIIC chair, Mr. Kurokawa drew a considerable response when he commented in an English report that the Fukushima Accident stemmed from a unique aspect of Japanese culture. We obviously need to be careful not to ascribe technical problems to cultural uniqueness. Nevertheless, cultural considerations are necessary to translate codified principles and guidelines into practice and to form a shared understanding with the public.

V. Conclusions

Simply put, all of the problems discussed in this commentary are associated with a poor interface between principles and the reality of the situation. In his capacity as the chair of the investigation committee, Mr. Hatamura rightly pointed out that the format alone does not ensure proper functioning and that the purpose cannot be shared by simply building a system (government, p. 446). The nuclear community must recognize its responsibility to convert this comment into reality. They must determine which principles can be effectively put into practice and then recommend them both on the frontline and to the relevant bodies. However, fulfilling this responsibility would be difficult for engineers and technicians alone. Consequently, there are high hopes that expertise from a wide spectrum of disciplines, including the humanities and social sciences, will also play a part. However, the first move must be made by stakeholders in the nuclear sector with due consideration given to their responsibilities.

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Commentary

Several Concerns on Nuclear Safety
−From Experiences of TEPCO Fukushima Daiichi Accident−

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The focus of this commentary is to present the lessons learned from the on-site events caused by the nuclear accident that occurred on March 11, 2011.

I. Loss and Subsequent Restoration of Expert Credibility

To gain public support, the following three steps are required: (i) experts should, in principle, reach a shared understanding that is essentially correct; (ii) information related to this understanding should be communicated effectively to non-experts; and (iii) this information should help non-experts develop a deeper understanding. However, the lessons learned from the accident that occurred at the Fukushima Daiichi Nuclear Power Plant suggest that the first step has a number of inadequacies, such as the following.

(1) The reactor accidents resulted from both an underestimation of the forces of nature (tsunami height) and inadequate preparedness for unanticipated events. Preparations for accidents were also inadequate because the routine observance of defined procedures led to complacency based on the mistaken assumption that reactor accidents would be extremely unlikely to occur in Japan.

(2) Experts failed to anticipate M9 earthquakes in the vicinity of Japan (although seismic ground motions are not expected to cause reactor accidents) and tsunamis of the scale that occurred. They were unable to form a collective opinion that could be reflected in the disaster management measures adopted by the national government.

(3) Experts failed to anticipate that a hydrogen explosion could occur after a core meltdown.

(Experts were aware that hydrogen had burned inside a primary containment vessel during the Three Mile Island (TMI) Accident that occurred in the United States in 1979. Furthermore, the possibility of hydrogen combustion occurring outside the primary containment vessels for boiling water reactors during a severe accident had already been mentioned in two studies conducted in Finland and the United States. However, there is no evidence that these studies were taken seriously. It seems that nuclear engineers did not have a shared awareness of the possible occurrence of a violent explosion of the type experienced in

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Fukushima. This is probably because research on reactor safety had been focused on the prevention of severe accidents without addressing their progression of actual severe accidents. Experts must reflect deeply on their failure to predict such accident progression properly at the critical moment where they should live up to the public trust conferred on them in light of their expertise.)

(4) Many conflicting opinions have been voiced about the health impact of low-dose radiation exposure.

(Experts with extensive research experience tend to share an almost identical opinion on this matter, which seems quite different from items (1) through (3) above. However, people from apparently different backgrounds have many dramatically different opinions. Such confusion is probably causing serious problems for those who were compelled to evacuate and other concerned individuals.)

It will not be easy for experts to restore public confidence, but a society that lacks confidence in its experts will remain in disarray. An important task for experts is to tenaciously continue to investigate the Fukushima Accident, establish safety measures, determine the latest findings, and communicate their opinions.

Many questions remain to be answered, including the extent of damage caused to reactor pressure vessels and primary containment vessels as well as the current locations of the nuclear fuel materials. In addition, some experts have claimed that the reactor building for Unit 2 avoided a hydrogen explosion because its blowout panel opened when Unit 1 exploded, but this panel is installed at a much lower level than the ceiling of the building, thus leaving a considerably large space above it. It remains unclear whether the opening of the blowout panel was enough to prevent the explosion and whether there were any other openings in the ceiling. The composition of the accumulated gas should also be assessed. Moreover, before the Fukushima Accident occurred, studies on the structural behavior of primary containment vessels had focused on the fulfillment of functions within their design conditions. Too few studies have been conducted to determine at which point their functions are lost beyond their design conditions (leakage of radioactive materials in the case of primary containment vessels). Their behavior should be urgently examined while taking into consideration the temperatures and pressures.

II. Infrequent Unplanned Shutdowns and Robust Reactor Safety

A high level of technological competence in Japan has been assumed to explain why unplanned shutdowns are extremely infrequent compared to the rest of the world. However, a clear distinction must be drawn between infrequent unplanned shutdowns and a high degree of safety at nuclear power plants. The fact that unplanned shutdowns are infrequent under moderate external forces of nature does not mean that nuclear power plants can be shut down safely under rare but extremely strong external forces of the nature.

Efforts to reduce unplanned shutdowns have most likely been reinforced in light of the need to sustain power generation, as well as based on the recognition that these shutdowns may cause concerns for nearby residents even though there is no direct effect on their safety. Arguably, an assessment should be conducted to also consider infrequent unplanned shutdowns as a possible cause for the lack of experience in operating emergency equipment.

A vital aspect of safety measures for nuclear power plants is to prevent an abnormality from escalating into an accident with an external release of radioactive materials. The utilities and regulatory authorities should both do their utmost to ensure this.

III. Aging Management

As part of the aging management measures adopted in Japan, extensive studies have been conducted to investigate changes associated with the aging of structures and power lines. Japan has been leading the world in terms of measures to address phenomena such as stress corrosion cracking, pipe thinning caused by internal flow, and fatigue damage caused by temperature fluctuations. Japan has a wealth of experience in performing preventive maintenance through the application of research findings at existing plants.

However, aging management needs to be bolstered from a broader perspective that goes beyond measures that deal with aging in materials over time. Among other things, the conditions need to be constantly revised to account for external forces of nature and a practical sense of the operating safety systems employed only in older plants should be cultivated.

For reference, the US approach to the service life of nuclear power plants is described here.

Initially, a service life of 40 years was specified in the United States. This period was determined by simply adopting the amortization period of 40 years that was used for fossil fuel plants in 1954. In fact, the Nuclear Regulatory Commission (NRC) of the United States admits in its report entitled "A Short History of Nuclear Regulation, 1946–2009" that the period was not specified with any consideration given to aging in structures over time, other technical factors, or safety. In the 1980s, the NRC carefully considered the possibility of extending the service life of nuclear power plants. It concluded that the service life could be extended by up to 20 years provided the latest safety verifications were performed. In the NRC report published in February 2013, a service life of 60 years was authorized for 73 out of the 104 reactors in the United States. Of these reactors, 17 had already been in service for more than 40 years. The report explains that the NRC is discussing this extension for 15 units and that applications are expected to be submitted for an additional 13 units.

IV. Importance of Continuous Improvements

Unlike the TMI Accident (USA) and the Chernobyl Accident (USSR), the Fukushima Accident was not caused by factors such as the neglecting of device failure, faulty reading of instruments, or inadequate safety considerations being given to plant performance surveys. It is important to clearly recognize that the accident could not have been prevented by simply observing the regulations that had been authorized internally or by regulatory authorities or by just repeating the same tasks as those conducted the previous day. False assumptions must be dispelled and a critical review must be conducted to enhance safety. Continuous improvements are vital.

Plant personnel did their utmost to respond to the Fukushima Accident. For instance, the fact that injection lines to the reactors were quickly installed immediately after the loss of power probably prevented a further escalation of the accident. Moreover, a monitoring vehicle was deployed at 5 p.m. on March 11 to routinely cover those monitoring posts that were no longer able to conduct measurements after the station blackout. Data on the radiation doses registered by this vehicle proved vital in examining the development of later events.

The failure to prevent this accident despite such efforts has given rise to some fundamental soul-searching. This experience highlights the importance of preparing equipment and conducting emergency response drills before exceptional events can occur.

V. Building the Technical Capacity of Regulatory Authority Personnel

One of the most important tasks carried out by regulatory authorities is to build up the technical capacity of its individual employees in charge of regulatory matters. Continual capacity building must be pursued so that the employees gain a better understanding of what reactor safety entails and what activities enhance reactor safety.

The NRC is a notable foreign organization that serves as an important reference. It gained the top rank under the evaluation system called “Best Places to Work” among U.S. government agencies for two consecutive years in 2009 and 2010. This evaluation is conducted based on various criteria, including capacity building for personnel, the manager’s capacity to run the organization, and teamwork. The majority of the staff at the NRC work there for a long time. Many experts with years of service in performing regulatory work are also trained through the provision of on-site experience to build up their technical competence. They conduct their own research and draft standards for regulation. In addition, they monitor efforts to enhance safety measures at the respective nuclear power plants. (The NRC systematically incorporates opinions of external academic experts into their regulatory standards as necessary.)

The NRC that exists today was not built overnight. In particular, nuclear power attracted severe public criticism in the United States after the TMI Accident of 1979. The NRC and various utilities undertook a process of trial and error to ensure the safety of nuclear facilities. Meanwhile, the generation that had given rise to the era of nuclear power reached retirement age while the number of students of nuclear energy dropped sharply in the aftermath of the TMI Accident. Such developments led to serious concerns over inadequate knowledge and technology transfers.

In response, the United States adopted long-term measures (e.g., college education programs) to encourage a new generation to participate in the nuclear sector. At present, the number of students specializing in nuclear energy has grown considerably compared to the level that existed before the TMI Accident. In light of how highly it is rated as a workplace, the NRC attracts many outstanding talents year after year. (Some speculate that a considerable number of former navy staff who have worked on nuclear submarines or aircraft carriers join the nuclear power sector including NRC. They further point out that, in striking contrast with its U.S. counterpart, the Japanese nuclear sector does not enjoy a sufficient supply of human resources from the military sector. In response to this speculation, an NRC commissioner explained that “a certain proportion of new recruits do have a navy background, but the military cannot match universities in terms of their ability to provide a reliable source of new recruits to sustain our activities. The number of graduates who are directly recruited to the NRC after completing their nuclear studies is much higher.”)

VI. Ongoing Discussions among Stakeholders

Efforts to ensure nuclear safety must be undertaken in various areas. In addition to regulatory authorities conducting a review of regulatory requirements, discussions should be held repeatedly by scientific communities, utilities, and industrial circles. These efforts should be conducted in tandem while also complementing one another.

A good example of a foreign standard that has been developed mainly by industrial circles is Section III of the "Boiler and Pressure Vessel Code" published by the American Society of Mechanical Engineers (ASME). Issued in 1963, this structural standard for the mechanical equipment employed in nuclear power plants has been honored and adopted in various forms by the regulatory authorities of not only the United States, but also many other countries around the world, including Japan.

In response to the Fukushima Accident, the ASME set up a taskforce headed by Dr. Diaz, who once served as the chair of the NRC. In June 2012, the taskforce proposed new nuclear safety measures in a presentation entitled "Forging a New Nuclear Safety Construct." Based on this proposal, a workshop was held in Washington D.C. in December 2012. Participants from industrial circles and regulatory bodies based in various countries around the world discussed how these measures should be implemented. Ms. Macfarlane, the incumbent NRC chair who was appointed last July, also attended the workshop and made a speech stressing the importance of the efforts made among industrial circles to enhance nuclear safety.

At the quarterly ASME meetings held to review the "Boiler and Pressure Vessel Code," many participants from the NRC voice their opinions as representatives of their respective regulatory authorities. At these meeting, reports of 10 pages or more are distributed to brief on the activities conducted by the NRC.

The following remarks made by Dr. Diaz in his presentation during the ANS 2012 Winter Meeting offer suggestions concerning the desirable relationship between regulatory authorities and utilities as well as public acceptance of reactor safety.

- On the "acceptability" of safety, the U.S. Appeals Court ruled as follows in 1987: "The level of adequate protection need not, and almost certainly will not, be the level of zero risk."
- The reality is that there is no such thing as zero risk, and for all technologies, including nuclear, a certain level of risk is/should be acceptable to society.
- There has to be a defined, fair, visible CONTRACT between regulators and operators, with accountability by and for all, that considers internal and external events and extends the protection to severe rare events.

VII. Conclusions

Our hearts go out to the many people who even now are forced to continue their lives as evacuees following their displacement due to the accident that occurred at TEPCO's Fukushima Daiichi Nuclear Power Plant. However, nuclear technologies remain vital for Japan in terms of not only supplying energy, but also providing medical diagnoses, conducting cancer treatments, carrying out industrial inspections, and so forth. Therefore, it remains essential that we continue to conduct nuclear-related research and foster the necessary human resource development.

Commentary

Proposal Strategy and Policy on Nuclear Safety for No-More Severe Accidents

-Proposal for Countermeasures to Prevent Severe Accidents at Nuclear Power Plants-

Committee on Prevention of Severe Accidents at Nuclear Power Plants

The 2011 off the Pacific Coast of Tohoku Earthquake, which had a magnitude of 9.0, and the catastrophic tsunami that followed on March 11, 2011, struck five nuclear power stations located on the Pacific coast, thereby triggering a severe accident involving an extensive release of radioactive materials at the Fukushima Daiichi Nuclear Power Plant (NPP) operated by the Tokyo Electric Power Company (TEPCO). It was Professor Hiroyuki Abe, the former president of Tohoku University, who proposed the establishment of the Committee on Prevention of Severe Accidents at Nuclear Power Plants with the following statement: "How could the severe accident that occurred at TEPCO's Fukushima Daiichi NPP have been prevented? We must lose no time in determining the necessary measures that should have been in place to prevent this accident. Given that a nuclear power plant is primarily a product of technological development, it is the mission of the scientists and engineers engaged in promoting nuclear technology and nuclear safety to address and clarify the measures necessary to prevent a severe accident." The committee was established according to his proposal.

Although the Fukushima Accident was caused by an immense tsunami that was triggered by a massive earthquake, scientists and engineers who have dedicated themselves to research and development in the nuclear technology field for so many years are overwhelmed with sorrow and regret for the broad and severe devastation suffered by local residents and the rest of the nation.

Vowing that such a severe accident will never happen again, nuclear scientists and engineers have gathered to address fundamental issues concerning the re-establishment of preventive measures based on scientific and technological grounds.

I. Introduction

Over 40 years have passed since light-water reactors (LWRs) were first introduced for commercial nuclear power generation in Japan. The experience that Japan has accumulated in relation to research results and technological developments aimed at resolving numerous past

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failures and accidents has helped fortify and enhance the technological basis of LWRs. Currently, Japan is leading the way in LWR technology globally in terms of reliability and safety.

During the 2011 off the Pacific Coast of Tohoku Earthquake that occurred on March 11, the Fukushima Daiichi Nuclear Power Plant (Tokyo Electric Power Company) and the Onagawa Nuclear Power Plant (Tohoku Electric Power Company) registered responses that exceeded their design basis with respect to some aspects of seismic motion. However, when the earthquake hit, the reactors were immediately scrammed to perform a normal shutdown, and all of the key safety components, structures and systems related to the cooling and isolation of radioactive materials were functional and judged to have not been directly affected by the earthquake [1)].

So, what caused this severe accident [a] at Fukushima Daiichi NPP?

The direct cause of the accident was that multiple overlapping tsunami waves that had been generated by multiple seismic fault movements along the ocean trench off the coast of the Fukushima Daiichi NPP struck the plant with a wave height exceeding 15 m, a magnitude that far exceeded the design basis. This was considered an unprecedented event that no one had anticipated.

Japan's trust in nuclear technology—including its systems and components—is founded on the high quality of its design and manufacturing within the spectrum of a defense-in-depth of up to Level 3 under the International Atomic Energy Agency (IAEA) standards indicated in **Table 1**. The design and manufacturing standards established in Japan produced systems and equipment with very high reliability within the scope of design. However, because sufficient consideration had not been given to design requirements in relation to severe accidents caused by extreme natural phenomena that exceed the design basis or the establishment of countermeasures for such events, the designed safety facilities failed to function during the Fukushima Daiichi Accident.

Consequently, the major issue to be addressed is the establishment of a systematic approach to preparing for and responding to severe accidents that exceed the design basis.

In a safety assessment for the restarting of an existing plant in operation, it is necessary to evaluate its adequacy in relation to design criteria up to Level 3 (based on accumulated

Table 1 Defense-in-depth levels of IAEA

	Levels of protection	Objective	Corresponding plant condition
Design basis	Level 1	Prevention of abnormal operations and failures	Normal operation
	Level 2	Control of abnormal operations and detection of failures	Anticipated operational occurrences (AOO)
	Level 3	Control of accidents within the design basis	Accidents within the design basis (A single, anticipated initiating event)
Beyond design basis	Level 4	Control of severe plant conditions, including prevention of accident progression and mitigation of the consequences of severe accidents	Multiple failures Severe accidents
Emergency response	Level 5	Mitigation of radiological consequences of significant releases of radioactive materials	(Disaster management)

[a] Severe accident: The term "severe accident" is conventionally used by regulatory bodies, but the term "major accident" is used in the Act for Establishment of the Nuclear Regulation Authority. This commentary adopts the commonly used term "severe accident" to convey the meaning of an event that far exceeds the design basis event, prevents proper core cooling or reactivity control by the means anticipated in the assessment of safety design, and leads to serious core damage.

reliability of the design and manufacturing processes). Furthermore, it is also necessary to extend severe accident management to within the spectrum of defense-in-depth Level 4 and implement a mechanism for ensuring continuous improvements in view of the devastating impact of the Fukushima Daiichi Accident. For this purpose, preparedness and response measures against large-scale earthquakes and tsunamis must be fully ensured and a prompt process for establishing appropriate measures against Level 4 incidents caused by factors other than earthquakes and tsunamis must be implemented by taking into account the specific design and siting conditions of each plant.

II. Analysis

1. Approach to Defense in Depth

Until now, ensuring the safety of nuclear reactor facilities in Japan has been focused on the management of design basis accidents [2, 3]. This approach was based on three principles: the three levels of defense-in-depth (prevention of abnormal operations and failures, control of abnormal operations, and control and mitigation of accidents within the design basis); the configuration of important systems based on single-failure criterion; and correspondence for assumed external events such as earthquakes and tsumanis, etc. within design basis.

However, after the Three Mile Island Accident in the United States and the Chernobyl Accident in the former Soviet Union, the global community became more keenly aware of the significance of the extended consideration of beyond design basis events, or severe accidents, and the enhancement of protection measures against such events. In Japan, this issue was discussed and examined by the now defunct Nuclear Safety Commission (NSC). In May 2002, the NSC made strong recommendations on beyond design basis events within the spectrum of defense-in-depth Level 4, encouraging utilities to independently establish accident management measures (AM; the prevention of severe accidents and mitigation of any consequences that may occur) and take the provisions necessary to accurately implement such measures in the event of an accident. The recommended accident management measures for preventing an incident escalating into a severe accident and mitigating any consequences that may occur included taking advantage of the capacity margin of existing safety systems, using the functions of existing systems for purposes beyond their design intention, and using systems newly installed for AM purposes. The NSC requested the utilities and the former Ministry of International Trade and Industry (MITI; later this authorization was transferred to the Nuclear Industrial and Safety Agency) to manage and report on accident management measures.

In accordance with this policy, MITI promoted measures against severe accidents through administrative guidance and asked utilities to report on the measures that they put in place. The safety measures carried out by utilities remained voluntary. Accidents that may escalate into severe accidents beyond the magnitude of the design basis accident were not explicitly regulated as events within the scope of Level 4 defense in depth. Practices in Japan, including the policy of addressing severe accidents in the design of a new plant, were not necessarily lagging behind global trends, but Japan failed to establish regulatory requirements that kept pace with other countries.

In June 2012, the Act for Establishment of the Nuclear Regulation Authority was enacted in response to the accident that occurred at the Fukushima Daiichi Nuclear Power Plant. This act marked a transition to the adoption of safety regulations that also postulate major natural disasters and terrorism. In other words, the prevention and mitigation of events that may lead to severe accidents with a magnitude beyond that of the design basis are classified as Level 4 defense in depth.

The necessary equipment, apparatus, and other items must be installed with sufficient consideration given to factors such as redundancy, diversity, independence, reliability, and importance classification.

2. Analysis of TEPCO's Fukushima Daiichi NPP Accident

When the earthquake hit the Fukushima Daiichi NPP on March 11, all of the operating plants scrammed automatically into a cold shutdown. However, the impact of the tsunami that followed far exceeded the design assumptions, so this outcome had not been given due consideration in the safety measures. The tsunami event triggered a common-cause failure of extensive systems, including the loss of redundant or diverse systems, thereby inducing station blackouts and a subsequent loss of core cooling, a loss of ultimate heat sink, and eventually core damage (core melt). This caused a hydrogen explosion and a failure to contain radioactive materials, which led to a significant release of radioactive substances into the environment. This catastrophe was initiated by an external event. This gives an overview of TEPCO's Fukushima Daiichi Accident[4)].

The key issues to be addressed are vulnerabilities in terms of the following: assumptions concerning the functional failure of multiple units; assumptions concerning common-cause failures and accidents; and measures for dealing with these conditions. Specifically, the simultaneous failures and functional loss of safety components installed in multiple units at a site, or the overlapping of multiple failures or accidents, were not taken into account in previous assumptions. The tsunami that struck the Fukushima Daiichi NPP induced multiple simultaneous component failures, including the loss of redundant components in multiple units all at once. The essential events that led to such a severe accident were 1) a station blackout; 2) a loss of cooling systems; and 3) a loss of ultimate heat sink.

On the other hand, inadequacies in terms of accident management include a failure to address the following: 1) deficiencies in or shortages of alternate power sources; 2) deficiencies in the alternate pump capabilities (e.g., fire engines); and 3) unanticipated events (station blackout, hydrogen explosion, containment vessel damage, etc.).

These inadequacies and deficiencies were the outcome of our own limited assumptions concerning accident scenarios, with no consideration whatsoever given to accidents like the unanticipated aspects of the Fukushima Daiichi Accident. Until then, accident scenarios had been based on assumptions concerning internal events initiated by a single failure of the constituting components. This approach was based on the assumption that, if a one-by-one analysis of such scenarios was performed thoroughly and systematically, it could serve as a replacement for a quantitative (objective) assessment to ensure plant safety. Damage to multiple units due to the simultaneous failure of components with the same functions and common-cause failures were considered extremely low probability events in past assessments. The postulation and consideration of worst-case scenarios are critically important. An inadequate understanding of the accident sequences—including when fuel damage begins, how a containment vessel is damaged, and what happens after a vessel is damaged—and a lack of measures to address them led to us only reacting to events and falling behind during the disaster at the Fukushima Daiichi NPP[5)].

III. Assessments

1. Measures for Unanticipated Events

− In nuclear safety, the fact that something was not anticipated is not an acceptable excuse. The regulatory body and utilities should establish a framework that facilitates emergency preparedness and responses for all credible natural disasters, human-induced and internal events, and other such eventualities by thoroughly examining and identifying them.

The magnitude of the 2011 off the Pacific coast of Tohoku earthquake and the subsequent catastrophic tsunami was far beyond the design assumptions. In view of the potential risk associated with the large amount of radioactive materials contained in the reactor core, it is not acceptable to disregard natural disasters or external human-induced events as something unanticipated in crisis management. Full consideration must be given to preventing any adverse consequences for members of the public in the vicinity and the environment that may arise due to a significant release of radioactive materials. This should be engraved in the minds of all those engaged in the design, construction and operation of nuclear plants and related facilities. A constant process of applying new technologies, expertise, and the results of R&D in the design, operation and regulatory requirements for nuclear plants is necessary.

Responsibility for the surveillance and monitoring of emergency preparedness and accident prevention measures rests with the government and the regulatory body under the nuclear safety regulatory framework. It is necessary to establish regulatory requirements for the biannual submission by the utilities of "Severe Accident Prevention Plans," which contain reports on credible accident scenarios for natural disasters, human events and internal events; response management plans; the implementation status of emergency response training; and other such information for each plant. The regulatory bodies must take responsibility for establishing a system for reviewing and approving the planned countermeasures. Going beyond the regulatory framework, utilities must constantly look out for any events that may lead to severe accidents and try to develop countermeasures.

2. Development of Performance-Requirement-Based Standards

− All of the safety review guidelines and standards should be reviewed and modified as necessary without any preconceptions for the establishment of a systematic, performance-requirement-based[b] regulatory framework.

A "Fundamental Concept on Nuclear Safety" should be established to ensure the safety of nuclear power plants in Japan by referring to the IAEA Safety Standards and tailoring them to the prevailing circumstances here. Based on this "Fundamental Concept of Nuclear Safety," a framework for safety objectives, performance objectives, and fundamental policies on safety regulations should be developed at an early stage.

In addition, for example, "Guideline 27: Design Considerations against Loss of Power" of the Safety Design Guidelines ("Regulatory Guide for Reviewing Safety Design of Light Water Nuclear Power Reactor Facilities") of the NSC stipulates that "a nuclear power plant shall be so designed to ensure safe shutdown and adequate cooling thereafter in case of a short-term station blackout (SBO)." However, the commentary for Guideline 27 states the following:

[b] Establishment of performance-requirement-based technical standards by the regulatory body: The regulatory body should establish technical standards (codes and regulations) that are focused on performance requirements but provide flexibility in the selection of specifications for achieving the required performance.

“the occurrence of a long-term SBO need not to be considered since recovery of a power transmission line or emergency diesel generator (EDG) should be expected.” This will also be a factor behind the total lack of measures against power loss in the event of an SBO incident. All key safety components and equipment should be instrumented so that the probability of a common-cause failure is kept as low as possible and to ensure redundancy. If this is not feasible, diversity in terms of a combination of different functions and a distributed arrangement should be considered. It is also necessary to clarify the requirements for seismic resistance and radiation resistance in “Guideline 44: Emergency Station in Nuclear Power Plant” and whether an isolated reactor cooling function should be included with respect to “Guideline 42: Reactor Shutdown Function from Outside of Control Room.” Together with the revision of the Seismic Design Guidelines (“Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities”), an independent set of guidelines on associated events, particularly tsunami events, should be established. Similarly, the Review Guide for Safety Evaluations should establish a safety assessment method for severe accidents within the domain of defense-in-depth Level 4.

As such, in parallel with a systematic reorganization of laws, governmental and ministerial ordinances, and technical standards, the government should entrust professional societies in the civilian sector with establishing codes and specifications (for the actual implementation of regulatory standards) to ensure the prompt application of the results of state-of-the-art technologies and promote a performance-requirement-based regulatory structure. A systematic, performance-requirement-based nuclear safety framework should be established as quickly as possible.

3. Enhancement of Management Measures and Human Resource Development

− Substantial management measures related to nuclear safety should be implemented and the quality of personnel directly involved in operations should be improved.

The quality of the onsite emergency staff who managed the accident undoubtedly influenced recovery operations at the Fukushima Daiichi NPP. Although the onsite staff had regular training, the fundamental concept of nuclear safety—i.e., the basis for the training and safety measures—did not anticipate a severe accident of this scale. Naturally, the operators cannot be blamed for any failure of their part in responding to this unanticipated emergency. At the same time, a more appropriate response could perhaps have been taken if the operators had acquired a basic understanding of nuclear power generation and nuclear reactions.

The sequence of events that lead to a severe accident will never progress along the lines of a scenario. Given this, it is necessary to stipulate the regulated assignment of accident management specialists with the following attributes to each nuclear power site, or preferably each plant: a thorough understanding of nuclear power generation systems and the ability to make accurate judgments concerning event sequences in order to provide the necessary directions to onsite staff. The accident management specialist should possess professional expertise and competence in accident management and be able to advise the site director on matters such as the installment of necessary facilities and the allocation of the staff required for the implementation of accident management. In an emergency, the accident management specialist will support the site director in deliberations, decision-making, and the authorization of accident management operations. The regulatory surveillance and monitoring officer assigned to each site should be a technical expert with the same qualifications as the accident management specialist and be responsible for ensuring safety by liaising with the utilities.

A “Severe Accident Management Procedure Manual” should be developed for each power plant, with each item having been confirmed on site (they should not be confirmed only through deskwork), and then submitted to the regulatory body and shared with the surveillance officer. Together with the "Severe Accident Prevention Plans," this manual should be reviewed and revised on a biannual basis, for example. Because of the expected complexity of the manual's content, the document should preferably be digitalized and made available to the operating staff and workers so that they can implement the measures promptly.

The education and training of plant and site directors, managers, duty supervisors, duty staff, and other personnel should be provided frequently and on a regular basis so that response actions can be taken promptly under any circumstances, day or night, and under extreme weather conditions. It is essential that management measures related to nuclear safety be implemented and enhanced and the quality of personnel be improved by both the utilities and the regulatory body. At the same time, the regulatory body, utilities and manufacturers should coordinate joint regular meetings for information sharing and open sessions or observe plant construction work and commissioning by other utilities for the overall enhancement of the nuclear power industry. Furthermore, it is preferable that academic societies comprised of experts in the nuclear field provide appropriate advice as necessary.

4. Continuous Efforts to Reduce Risks and Share Information with the Public

− The government and utilities are responsible for the continuing process of building consensus and gaining public confidence concerning the benefits and risks of nuclear power generation. Scientists and experts in the nuclear technology field must also establish and maintain dialogue with the public on the benefits of nuclear power generation, which does not necessarily guarantee absolute safety so it should be balanced against the risks.

When communicating with the public in the past, the utilities (and related parties involved in nuclear technology) have emphasized the absolute safety, or the safety myth, of nuclear power plants. Some point out that this may be one of the factors to have hampered the appropriate establishment of severe accident management.

Dedicated and continued efforts in fostering an attitude that prioritizes nuclear safety are essential. Such efforts are required of the utilities and regulatory body as well as scientists and engineers in the field.

A continuing process of verifying and validating nuclear safety should be established by incorporating new scientific and technological findings in related fields, including natural disasters and human events, as well as the operating experiences of facilities and the results of safety research. To ensure the process of verifying and validating nuclear safety, it is necessary to enhance transparency in the examination and application of new findings as well as communication with the public regarding the status and issues.

The significance of the risks involved was recognized by some nuclear technology experts and part of the nuclear industry community. Research had been conducted into severe accidents and design studies for new LWRs equipped with severe accident countermeasures. Unfortunately, however, the overall awareness and understanding that a portion of the community had of the risks involved were not utilized in the severe accident management of existing NPPs. As scientists, researchers, and engineers, we must reflect deeply on our failure to raise awareness of these risks among utilities, regulatory bodies, and the public as well as the lack of adequate explanations of the necessary measures. At the very least, we need to admit that our efforts to do so were not sufficiently proactive.

Professional societies should and must establish dialogue with the public to formulate a shared recognition of risk.

The following are some points that should be noted in relation to establishing dialogue with the public.

(1) Benefits and risks

There is no absolute safety associated with any particular kind of system (railways, aircraft, cars, etc.). The benefits generated by the use of nuclear power, like those of other types of systems, will inevitably involve physical, mental, or financial risks.

(2) Issues concerning minimizing risk (safety goals) [6)]

Nuclear power generation offers various advantages over other energy sources. However, it involves the generation of radioactive nuclides (or fission products) that arise from the enormous amount of energy released by the reaction within the atomic nuclei, as uranium or plutonium. The reactor needs to be cooled continuously after a shutdown because of the decay heat generated by the fission products, and the radioactive nuclides must be contained to prevent their release into the environment. In the Fukushima Daiichi NPP Accident, safety functions related to cooling and containment failed, thereby subjecting the local and national public to devastating damage and losses. Accident risks must be minimized to the extent possible, but how much risk can be accepted as safe?

"How safe is safe enough" has been part of the international agenda, so many countries have adopted safety goals presented as probabilistic figures and are using them to effectively complement deterministic rules. In Japan, the former Nuclear Safety Commission (NSC) proposed its "Safety Goals (draft)" after examining this issue. In their proposal, the safety goals were given the role of specifying the extent to which safety regulations by the government will be imposed on utilities' management of risks associated with low probability events. The proposal quantitatively clarified the required levels of risks associated with the use of nuclear energy that need to be regulated. It was the intention of the NSC that this clear definition should enhance the transparency, predictability, rationality, and consistency of the regulatory activities. It was also expected that safety goals expressed in terms of the risk to the public would enable the government and the public to exchange views effectively and efficiently on various regulatory activities, including the development of guidelines and standards. The proposed goals were presented on three levels: qualitative goals, quantitative goals, and performance goals. The qualitative goals (i.e., the top level goals) require that the likelihood of any adverse health consequences to the public arising from the release of radiation or radioactive materials due to the use of nuclear energy should not significantly increase health risks to the public to a level above that expected from everyday life.

Quantitative goals present specific numerical values that are embodied in qualitative goals. For example, the mean value of an acute fatality risk due to radiation exposure resulting from a nuclear facility accident in relation to members of the public in the vicinity of the site boundary of the nuclear installation shall not exceed the probability of approximately 1×10^{-6}per year, and the mean value of the fatality risk due to cancer caused by radiation exposure resulting from a nuclear facility accident in relation to members of the public residing in the area but at some distance from the facility should not exceed the probability of approximately 1×10^{-6} per year. The people that these goals apply to are limited to residents living in the vicinity of the site boundary of the nuclear installation, and the risk of radiation exposure is 1/50 of the annual fatality rate for car accidents. The performance goals use parameters describing the characteristics of the facilities to express rough indicators that allow conformity with the safety goals to be easily verified. The given figures are the core damage frequency (CDF) of 10^{-4}/reactor year and the containment failure frequency (CFF) of

10^{-5}/reactor year (representing the facility performance in relation to the integrity of the reactor core and containment function) in accident scenarios including internal and external initiating events (except for malicious or deliberate human events). However, these figures are not to be applied as fixed values. The requirement is as follows: "In all activities involving a nuclear installation, including its design, construction and operation, reasonably feasible risk reduction measures must be planned and implemented to ensure that the radiation risk to the public does not exceed 1 millionth annually and that, if necessary measures are planned and implemented on the basis of the proposed requirements described above, then it would not mean that the safety goal is not fulfilled even if the result of a risk assessment exceeds the value of 1 millionth." (Refer to "Interim Report on the Investigation and Review of Safety Goals," Special Committee on Safety Goals, Nuclear Safety Commission, December 2003.)

In view of TEPCO's Fukushima Daiichi NPP Accident, the method used in the selection of the above figures and indices should perhaps be modified. However, establishing dialogue with the public is extremely important in building consensus concerning the level of risk that is acceptable and can be agreed on by the people. The results of an examination incorporated into the draft Safety Goals would be useful as the basis for such dialogue.

(3) Providing sufficient information

A prerequisite for the effective use of safety goals and performance goals is for the results of a probabilistic risk assessment (PRA) to be explained together with the limitations and uncertainties associated with the assessment. For example, in NSC's draft "Safety Goals," both internal and external events need to be considered as initiating events. Unfortunately, a PRA[c] for external events such as earthquakes and tsunamis had not been conducted at TEPCO's Fukushima Daiichi NPP. This failure revealed that comparisons between assessment results and safety goals are meaningless unless risks are assessed by taking into account a wide range of events. Going forward, the risks involved should be explained to the public by clarifying the scope of the assessment, the policy for assessing any risk factors beyond this scope, and how any remaining risks are taken into account. If it is difficult to determine whether a safety goal has been satisfied due to a high degree of uncertainty concerning the assessment method, it is important to explain how much of a reasonably feasible effort is being made. We need to understand that discussions on the acceptance of the risks involved cannot take place otherwise. The efforts involved in providing the details and grounds for a risk assessment are closely tied to the activities conducted to gain the understanding of the public on the meaning and importance of various specific safety measures taken by the regulatory body and utilities. For this reason, these activities should be carried out in parallel.

IV. Recommendations

Based on the above discussions, our committee recommends the following principles.

Recommendation 1:

In nuclear safety, the fact that something (any natural hazard, human error, etc.) was not anticipated is not an acceptable excuse. Efforts for eliminating unanticipated events are crucially important.

Recommendation 2:

A framework for ensuring nuclear safety should be established, whereby, safety review

[c] PRA/PSA: The terms "probabilistic risk assessment" (PRA) and "probabilistic safety assessment" (PSA) are synonyms for methods used to evaluate nuclear safety.

guidelines and standards on safety should be reevaluated without being subject to preconceptions for developing a globally respected framework of nuclear safety.

Recommendation 3:

All related parties in the nuclear community should recognize responsibilities commensurate with assigned roles and establish the overriding priority in ensuring safety. The regulatory body, in particular, must determine fundamental principles for the prevention, and mitigation, of the consequences of severe accidents (defense-in-depth Level 4) by hearing the opinions of a broad spectrum of experts. The utilities should determine severe accident measures and effectively implement them with a sense of vigilance.

Recommendation 4:

The government and the utilities should independently or jointly—together with scientists and experts in the nuclear technology field through professional societies—establish risk communication with the public concerning nuclear power generation as well as promote activities aimed at establishing public consensus on the benefits and risks of nuclear power generation.

The following recommended specific measures are intended to support the above recommendations.

Recommendation 5:

The regulatory body should regulate plans and inspections on severe accident prevention and mitigation measures within the domain of defense-in-depth Level 4 that are proposed and prepared by the utilities. In the examination of such measures, all internal events (including human error events, etc.), natural phenomena and human-induced events associated with severe accidents should be included. By liaising with experts and utilities, the regulatory body should construct effective measures (accident management) by conducting deliberations on the combination of a broad spectrum of response strategies, including the use of a variety of components and equipment, for preventing severe accidents and mitigating the consequences if one occurs.

Recommendation 6:

Reliability of safety functions corresponding to the domain of defense-in-depth Level 4 should be ensured through elimination of common-cause failures, by ensuring independent effectiveness through distributed arrangement and diversification of safety functions.

Recommendation 7:

Specific measures for accident management should be flexible as to address unanticipated conditions which may not be dealt with by permanent facilities. Thus, transportable and mobile facilities (fixed on vehicles) and redundant connections should be provided for flexibly coping with all circumstances.

Recommendation 8:

Utilities should assign onsite accident management specialist(s) with a thorough understanding of nuclear power generation systems, having the competence to accurately understand or recognize situations likely to occur in a nuclear reactor under accident conditions and the ability to make appropriate judgments in providing necessary directions to onsite staff.

Recommendation 9:

Utilities should prepare an accident management procedure manual in which each item must be confirmed on site on the basis that education, training, drills and exercises under all credible conditions should be fully provided to the staff.

Recommendation 10:

The regulatory body should conduct inspections and surveillance on accident management without omission. Utilities and the regulatory body should independently, or in cooperation, carry out reassessments for the continued enhancement of accident management.

V. Conclusions

Our committee hopes that this commentary will provide scientists, engineers, and other persons involved in the nuclear sector with input materials for discussions on preventing the recurrence of a severe accident. We also hope that it will help the general public to consider the risk-benefit trade-off involved in nuclear power generation.

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Lastly, the co-authors of this commentary are listed below.

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Design Basis Ground Motion Required on New Regulatory Guide
−Introduction of Lessons Learned from Recent Disastrous Earthquakes−

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The Nuclear Regulation Authority is developing new regulatory standards in response to the disaster that occurred at the Fukushima Daiichi Nuclear Power Plant operated by the Tokyo Electric Power Company (TEPCO). As well as providing an explanation of the requirements of the new regulatory standards, this commentary describes changes in the evaluation of the design basis seismic ground motions to be established as the basis of seismic design. It also presents new findings concerning the damage sustained in the 2011 Tohoku earthquake (Mw 9.0) and other recent destructive earthquakes to explain how these findings may help secure advancements in the evaluation of design basis seismic ground motions.

I. Introduction

On March 11, 2011, a giant earthquake occurred at 14:46 off the Pacific coast of Tohoku. In the morning of that day, the Special Committee on Seismic Safety Evaluations of the former Nuclear Safety Commission conducted a review of the Tokai Daini Nuclear Power Plant operated by the Japan Atomic Power Company (JAPC). Ironically, the review had just validated the method by which active faults were identified as well as the evaluation conducted using design basis seismic ground motions and the seismic safety of major facilities (seismic safety backcheck). The moment magnitude (Mw) of the earthquake was 9.0, making it the largest ever to have been recorded by the Japan Meteorological Agency (JMA). This magnitude scale was adopted because it has a wider scope than the magnitude scale usually adopted by the JMA (Mj). The enormous tsunami that the earthquake triggered inflicted widespread damage along the Pacific coast. On March 6, 2013, the National Policy Agency announced that this disaster had resulted in 15,881 deaths and 2,676 missing persons. The scale of the tsunami induced by this earthquake far exceeded that anticipated by TEPCO for the Fukushima Daiichi Nuclear Power Plant. The station blackout caused by the tsunami impaired the cooling function of the nuclear reactors, which led to a core meltdown, a hydrogen explosion, and ultimately to a severe and grievous nuclear disaster involving the leakage and dispersal of radioactive materials. Two years later, the circumstances surrounding nuclear

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power plants have changed substantially.

The Nuclear Regulation Authority (NRA) has been established as an agency affiliated to the Ministry of the Environment (MOE). The tasks formerly handled by organizations such as the Nuclear Safety Commission and the Nuclear and Industry Safety Agency were unified under the newly established NRA Secretariat. Prompted by the disaster that struck the Fukushima Daiichi Nuclear Power Plant, the NRA is working urgently to develop new safety standards and revise guidelines for nuclear disaster countermeasures.

In relation to the topic covered in this commentary, the public is concerned about not only whether faults located at the site or just below nuclear power plant facilities with important safety functions are active faults (fracture zones) to be considered in seismic designs, but also how the NRA defines this through the following procedures. The NRA is expected to convene a panel of experts to discuss how such active faults should be evaluated in an appropriate procedure and deliver an objective judgment on the conclusion based on scientific findings.

The new regulatory standards for earthquakes and tsunamis require that facilities with important safety functions be constructed on ground that has been confirmed to have no exposure to active faults. The expert panel is expected to conduct careful discussions based on scientific facts as their judgment will have decisive implications.

With the above in mind, this commentary begins by explaining how the evaluation of design basis seismic ground motions has advanced as a crucial element in terms of the seismic safety of nuclear power plants. It describes the process by which the Regulatory Guide for Reviewing the Seismic Design of Commercial Nuclear Reactor Facilities (established in July 1981 and revised in September 2006) was refined to produce the new regulatory standards for earthquakes and tsunamis (enforcement scheduled for July 2013). The commentary then explains how the lessons learned from the 2011 Tohoku earthquake and other recent destructive earthquakes have been incorporated into this refinement process. A design basis seismic ground motion provides a vital nexus between the identification of active faults, the evaluation of the magnitude of resulting earthquakes, and the necessary seismic designs for key facilities and equipment. Obviously, it is vital for this ground motion to be determined by incorporating new findings from observation data and other scientific evidence.

II. Evolution of the Evaluation of Design Basis Seismic Ground Motions for the Seismic Design of Nuclear Power Plants

In September 1978, the Japanese Atomic Energy Commission (AEC) established the original guidelines for the seismic design of commercial nuclear power plants. In October of the same year, the Nuclear Safety Commission (NSC) was separated from the AEC to form an independent organization (the NSC was subsequently transferred from the General Administrative Office of the Cabinet to the Cabinet Office in 2001 as a part of a government reorganization). Following a partial revision of the original guidelines, the NSC established the Regulatory Guide for Reviewing the Seismic Design of Commercial Nuclear Reactor Facilities (hereinafter referred to as the “Seismic Guide”) in July 1981. The Seismic Guide was established based on engineering judgments related to earlier experiences obtained from safety reviews, seismologic and geologic findings, and so forth. Its basic principles were presented in the Regulatory Guide for Reviewing the Safety Design of Commercial Light Water Nuclear Reactor Facilities, which was established by the AEC in June 1977. After that, discussions concerning a revision of the Seismic Guide began in 2002 based on new findings in seismology, earthquake engineering, and other relevant fields as well as dramatic improvements and advancements in anti-seismic technologies. A significant trigger for this revision was the occurrence of the Great Hanshin earthquake, which struck in 1995 with a magnitude of Mj 7.3. Discussions on this revision took four years. After an overhaul, the Revised Seismic Guide was established in September 2006 by the former NSC. Subsequently, seismic backchecks were conducted by the former Nuclear and Industrial Safety Agency (NISA) and the former NSC based on the Revised Seismic Guide at each of Japan's 54 nuclear power plants. Meanwhile, these rigorous backchecks continuously incorporated findings from later destructive earthquakes in Japan (e.g., the 2007 Chuetsu offshore earthquake (Mj 6.8), the 2007 Noto earthquake (Mj 6.9), and the 2009 Shizuoka earthquake (Mj 6.5)) as they became available.

The 2011 Tohoku earthquake (Mw 9.0) marked another turning point. A review team was established at the NRA to discuss new safety design standards for commercial light water reactor facilities in relation to addressing earthquakes and tsunamis. A skeleton plan for developing these new regulatory standards for earthquakes and tsunamis was formulated. Following the completion of a public comment, work is under way toward enforcement of these standards in July 2013. In the new regulatory standards, numerous new safety design requirements related to tsunamis were added in consideration of the fact that the disaster at the Fukushima Daiichi Nuclear Power Plant was caused by the 2011 Tohoku earthquake triggering a tsunami of a scale that far exceeded expectations. Although details were omitted, additional rigorous requirements included measures for preventing tsunamis from being able to reach and flood the premises of key facilities directly. As the above demonstrates, the devastation caused by destructive earthquakes prompted efforts to ensure and enhance the seismic safety of nuclear power plants. This section focuses on design basis seismic ground motions as essential inputs in the development of seismic designs. **Table 1** summarizes important changes in the formulation of design basis seismic ground motions.

Extremely novel and unique concepts have been adopted in the dynamic analysis conducted alongside static analysis for vital As-class, A-class, or S-class facilities (the As-class

Table 1 Important changes in the formulation of design basis seismic ground motions

Item	Original Seismic Guide (1981)	Revised Seismic Guide (2006)	New regulatory standards for tsunamis and earthquakes
Classification by importance	Four categories (As, A, B, and C)	Three categories (S, B, and C)	Three categories (S, B, and C)
Assigned types of earthquakes	Historical earthquakes Inland crustal earthquakes (triggered by active faults)	Inland crustal earthquakes (triggered by active faults), interplate earthquakes, and intraplate earthquakes	Inland crustal earthquakes (triggered by active faults), interplate earthquakes, and intraplate earthquakes
Assessment of active faults	Dating back 10,000 years (for S_1 earthquakes) Dating back 50,000 years (for S_2 earthquakes)	Dating back to the Late Pleistocene (ca. 120,000–130,000 years ago) or even earlier depending on the survey results	Dating back to the Late Pleistocene (ca. 120,000–130,000 years ago) or even to the Middle Pleistocene (ca. 400,000 years ago) depending on the survey results
Epicentral earthquakes	M 6.5 (hypocentral distance of 10 km)	Defined as seismic ground motions with no specific epicenters (defined as ground motions instead of relying on a magnitude)	Defined as seismic ground motions with no specific epicenters (definition as ground motions instead of relying on a magnitude) (latest findings must be reflected)
Assessment of seismic ground motions	Assessment of two types of design basis seismic ground motions (S_1 and S_2) based on a response spectrum method (point source evaluation: Osaki spectra, etc.)	A combination of two methods employed with respect to design basis seismic ground motions: one method based on a response spectrum (e.g., Taisen spectrum) and another based on a fault model	A combination of two methods employed with respect to design basis seismic ground motions: one method based on a response spectrum (e.g., Taisen spectrum) and another based on a fault model
Tsunamis	No rules	Simple rules as events associated with earthquakes	Rules are defined for the assessment of design basis tsunamis and the safety design for a tsunami

and A-class categories were integrated in the S-class category in the Revised Seismic Guide (2006)). The original Seismic Guide (1981) required design basis seismic ground motions to postulate seismic activity along active faults in addition to historical earthquakes experienced in the past. Design basis seismic ground motions S1 and S2 in the Seismic Guide (1981) have been evaluated by postulating two types of earthquakes (the maximum design basis earthquake and an extreme design basis earthquake) depending on the level of seismic activity along active faults. A requirement to postulate a hypothetical epicentral earthquake with a magnitude of Mj 6.5 was added to the evaluation of S2. As key criteria for the level of seismic activity along active faults, a timeframe encompassing the past 10,000 years was assigned for determining the maximum design basis earthquake, while a timeframe encompassing the past 50,000 years was assigned for determining an improbable extreme design earthquake. In the Revised Seismic Guide (2006), the definition of active faults was changed to cover activity that undeniably took place in the Late Pleistocene (ca. 120,000–130,000 years ago) or later. A newly introduced judgment criterion was the presence of any fault displacement or deformation identified in the last interglacial strata or on the geomorphic surface.

According to the new standards, active faults must be investigated by integrating geomorphological, geological, and geophysical methods. In the identification process, a comprehensive judgment was required by combining these methods depending on the distance of each active fault from the target site. In the Revised Seismic Guide (2006), earthquakes that must be considered for seismic designs are called “earthquakes for investigation.” Three types of such earthquakes must be assigned taking into consideration the modes of earthquakes, etc.: inland crustal earthquakes triggered by active faults (including those in the near offshore areas of the coasts), interplate earthquakes, and oceanic intraplate earthquakes (**Figure 1**). The same definition of active faults and the same method for selecting earthquakes for investigation were carried over to the new regulatory standards for earthquakes and tsunamis. Importantly, a clarification was added to the effect that active faults must be defined as dating back to the Middle Pleistocene (ca. 400,000 years ago) if a clear judgment cannot be made on the active faults for the Late Pleistocene or later. Reportedly, this is a clarification to ensure that the Revised Seismic Guide (2006) can be implemented properly rather than a change to the definition of active faults.

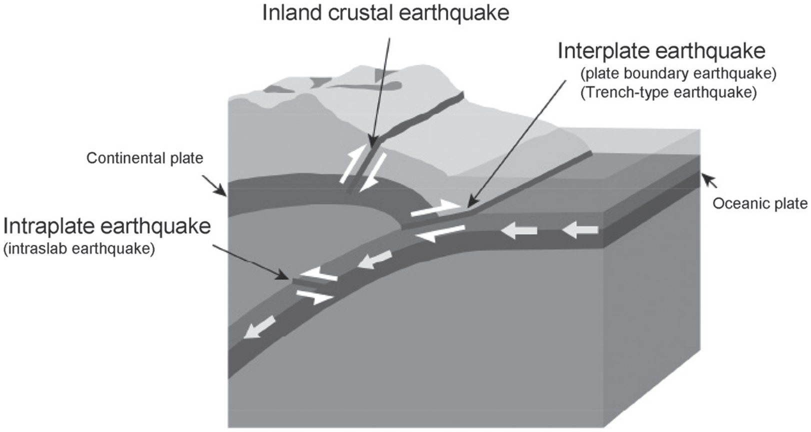

Figure 1 Earthquakes for investigation that must be considered in determining the design basis seismic ground motions

An earthquake is essentially a shearing rupture that spreads over a finite fault plane. The original Seismic Guide (1981) recommended a method for simulating design basis seismic ground motions empirically for an assessment. More specifically, an empirical spectrum (spectrum that expresses the intensity of a ground motion in a period, such as the Osaki spectrum, for example) was applied to a simple model of an earthquake source expressed using the scale (magnitude) and distance from the hypocenter to the target site.

The Revised Seismic Guide (2006) required that the assessment method based on the fault model advanced following the 1995 Kobe earthquake be applied in combination with the compilation of new findings in seismology, earthquake engineering, and other relevant fields. This guide clarified that the results obtained using this method should be prioritized if a source fault is close to the site. The effectiveness of this type of fault model in the assessment of design basis seismic ground motions is discussed in the next chapter. The design basis seismic ground motions assessed in this manner were treated as seismic ground motions with specific epicenters, and they were carried over to the new regulatory standards.

Nevertheless, even detailed surveys, including active fault surveys, cannot assess all possible earthquakes triggered near a site. Therefore, the guide required that all applications commonly consider seismic ground motions defined with no specific epicenters based on observation records. This requirement is the same as that stipulated in the original Seismic Guide (1981) for all applications to consider ground motions from a hypothetical epicentral earthquake with a magnitude of Mj 6.5. The revision was presumably encouraged by the fact that the development of earthquake observation networks in Japan and around the world had made it possible to obtain observation data in near source areas. Another possible reason is the validation of a magnitude of Mj 6.5 and the reliability of near source ground motion predictions due to an Mj 6.5 earthquake. These ground motions define the minimum levels of external forces generated by earthquakes, and they must be continuously revised based on accumulated observation records. The latest findings have been adopted for the implementation of the new regulatory standards for earthquakes and tsunamis.

The basic policy of the Revised Seismic Guide (2006) clarified the need to consider the existence of residual risks (i.e., risks associated with severe damage to facilities, massive releases of radioactive materials from facilities, and resultant disasters involving public exposure to radiation) and required that efforts be made to minimize residual risks by giving appropriate attention to the possibility of seismic ground motions being larger than the design basis seismic ground motions. In practice, however, this guide required that consideration be given to the probability of seismic ground motions exceeding the design basis. Residual risks had not been addressed sufficiently. There was no mention of specific risks and tsunamis were considered only as events associated with earthquakes. The concept of these residual risks was carried over to the new regulatory standards for earthquakes and tsunamis, which require not only reinforced designs to withstand earthquakes, tsunamis, and other external forces, but also countermeasures against severe accidents that may occur if the design basis earthquakes are exceeded.

Lastly, as mentioned at the beginning of this commentary, the new regulatory standards for earthquakes and tsunamis require that important facilities to safety be constructed on ground without any exposure to faults and the like that may become active. In these standards, faults and the like include not only faults that trigger earthquakes, but also those that may secondarily cause a permanent displacement or a slip surface of a landslide that cuts across any support foundation. This requirement has great relevance to the debate over on-site faults, which is obscuring the relationship between active faults and the seismic safety of nuclear power plants. It seems that discussions involving experts from many different fields will be extremely important in reconsidering what active faults are and how their activities affect nuclear power plants in terms of residual risks.

III. Overview and Incorporation of Findings from Recent Earthquakes

Destructive earthquakes involving casualties or property damage (**Figure 2**) have struck many parts of Japan since the 1995 Kobe earthquake prompted the revision of the Seismic Guide. Such earthquakes can be divided into three categories taking into consideration their modes, as illustrated in Figure 1. Some of these earthquakes had a strong impact on discussions concerning the seismic safety of nuclear power plants. Valuable data was obtained from the 1995 Kobe earthquake with the aim of understanding the relationship between an earthquake and an active fault (Rokko-Awaji fault zone) and identifying the characteristics and mechanisms of ground motions near the source. This data led to the development and practical application of ground motion predictions based on fault models [1)]. This effective ground motion prediction method based on fault models is also required in the field of nuclear energy under the Revised Seismic Guide (2006) and the new regulatory standards for earthquakes and tsunamis for assigning design basis seismic ground motions. Some time later, the 2007 Chuetsu offshore earthquake (Mj 6.8) directly struck TEPCO's Kashiwazaki-Kariwa Nuclear Power Plant right in the middle of a seismic backcheck that was being conducted in accordance with the Revised Seismic Guide (2006). The intensity of the observed ground motion easily exceeded (about double) the level that would be postulated based on the original

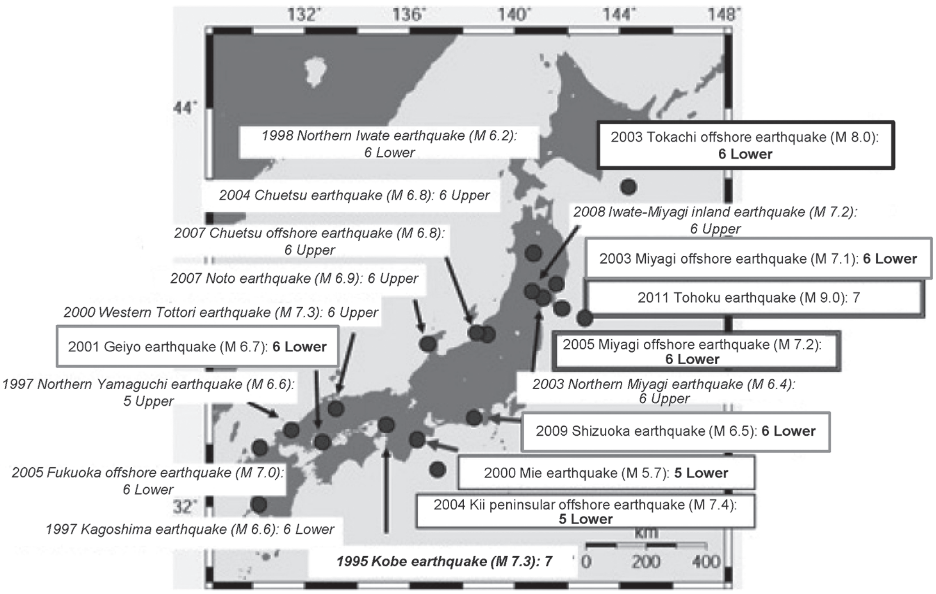

Figure 2 Distribution of the 1995 Kobe earthquake and subsequent destructive earthquakes
A single-border box indicates an intraplate earthquake, a double-border box indicates an interplate earthquake, and other boxes indicate inland crustal earthquakes. The name of each earthquake is followed by the JMA magnitude and the observed maximum seismic intensity according to the JMA scale.

Seismic Guide (1981). The reported seismic intensity of the earthquake at the site was around 7 on the JMA scale. All of the reactors that were in operation shut down properly and no problems arose with regard to the cooling of reactors. All of the important safety functions for the shutting down, cooling of reactors, and containment of radioactive materials were maintained. A later survey found that the earthquake had caused no noticeable damage to important facilities and equipment. The importance of safety margins in the design was pointed out.

This earthquake (1995, Kobe) posed some questions for us. First of all, where was the fault that triggered it? Had this fault been recognized before the earthquake? Sufficiently precise data could not be obtained immediately after the earthquake. The answers to these questions were found a few months later. An investigation clarified that the source fault mainly inclined to the south east, which largely corresponded to an active fault (F-B fault) that had already been identified. Nonetheless, further discussions were necessary to determine whether a seismic source fault can be identified before an earthquake with a medium magnitude of about Mj 6.8. As mentioned earlier, the magnitude corresponds to ground motions with no specific epicenters.

However, could the observed ground motions be predicted as being those from an earthquake with a magnitude of Mj 6.8 before the earthquake occurred? An examination of the source model began immediately after the earthquake. Various analyses revealed that the stress drop in the strong motion generation area (SMGA), which generated short-period ground motions, was slightly larger (about 1.5 times) than the average level for past inland crustal earthquakes. This finding was consistent with the attenuation characteristics of the maximum amplitude. The extremely large maximum amplitude of the observed ground motions in Kashiwazaki-Kariwa Unit 1 proved to be the product of the propagation path characteristics of the seismic waves (i.e., the focusing effect of seismic waves caused by folding). These findings were carried over to the new regulatory standards for earthquakes and tsunamis. This served as a reminder of the importance of conducting surveys on underground structures and the subsequent application for a model based on a fault model.

A similar event took place at the Hamaoka Nuclear Power Plant. During the 2009 Shizuoka earthquake (Mj 6.5), Unit 5 reported a significantly stronger shaking intensity than other units at the same site. Although surveys and analyses are still being conducted, the findings so far point to the possible amplification of the ground motion caused by the low-velocity layer just beneath Unit 5, rather than by the effect caused by the folding structure that occurred around the Kashiwazaki-Kariwa Plant. According to the new regulatory standards for earthquakes and tsunamis, these findings require consideration to be given to the three-dimensional underground structure of the site and the surrounding area, as necessary. Nonetheless, it is debatable whether the phenomenon that occurred at the Hamaoka Plant could have been predicted by any viable calculation of the propagation of the seismic waves based on a three-dimensional model of the underground structure. Given this, it is important to strengthen earthquake observations and to continue analyzing and investigating as much data as possible concerning earthquakes that affect nuclear power plants, and thereby assign design basis seismic ground motions more precisely.

Lastly, the following describes the implications of the 2011 Tohoku earthquake. Located in the northeastern part of Japan, Tohoku has experienced a series of major earthquakes triggered along the Japan Trench by the subducting Pacific Plate. As **Figure 3** demonstrates, the Headquarters for Earthquake Research Promotion had already publicized its long-term assessment of likely earthquakes (scales and probabilities) according to the postulated source zones off the coast between Sanriku and Boso based on records of past earthquakes with a

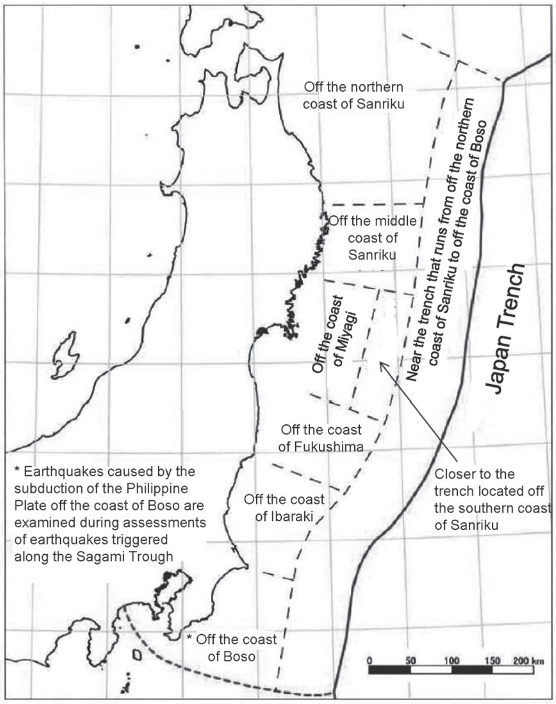

Figure 3 Target areas for the long-term evaluation of seismic activity by the Headquarters for Earthquake Research Promotion and Earthquake Research Committee from off the coast of Sanriku to off the coast of Boso

magnitude of around Mj 7 and 8 [2].

The 1995 Kobe earthquake prompted the nationwide development of networks for observing strong ground motions, such as the K-NET and KiK-net networks developed by the National Research Institute for Earth Science and Disaster Prevention (NIED). **Figure 4** presents part of the observation records from Aomori in the north to Chiba in the south using aligned timelines. Valuable observation records have been obtained from the Fukushima Daiichi Nuclear Power Plant and all of the other nuclear power plants along the Pacific coast. Figure 4 demonstrates that a characteristic ground motion was recorded in each region. Although two distinct wave groups were recorded in Miyagi and further to the north, only one wave group was recorded in Ibaraki and Chiba. Located in-between these regions, Fukushima reported a very complex wave group composition. In Figure 4, the travel time for each wave group (i.e., the time required for a seismic ground motion to travel from the epicenter to a site) was represented with a dashed line (a constant propagation velocity would have been expressed with a straight line). **Figure 5** presents a source model with five SMGAs based on the assumption that each intersection of a dashed line corresponds to a source area (SMGA) [3] that generated a wave group. This model was proposed to explain seismic ground motions with periods of 0.1 to 10 seconds, so it cannot provide an entire source process for the 2011 Tohoku earthquake. We can determine the entire source process from **Figure 6**, which shows that the source model (slip distribution) [4] estimated using the giant tsunami complements the model shown in Figure 5 to explain the observed strong ground motions.

Given that the magnitude of the earthquake could not be anticipated, what about the prediction of seismic ground motions? Thanks to the availability of numerous observation

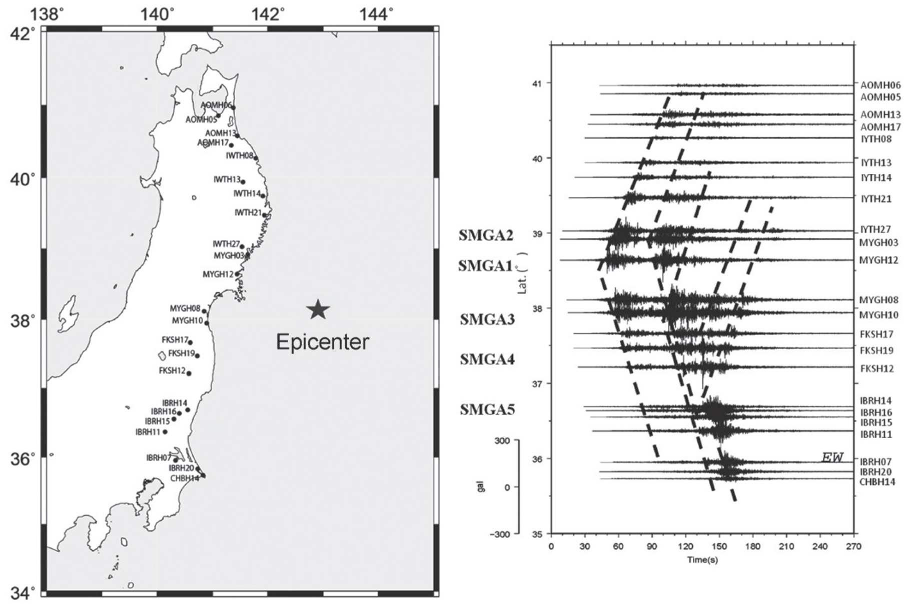

Figure 4 Acceleration waveforms observed during the 2011 Tohoku earthquake and the observation points (source: KiK-net (NIED))
SMGAs 1 to 5 correspond respectively to the five SMGAs shown in Figure 5.

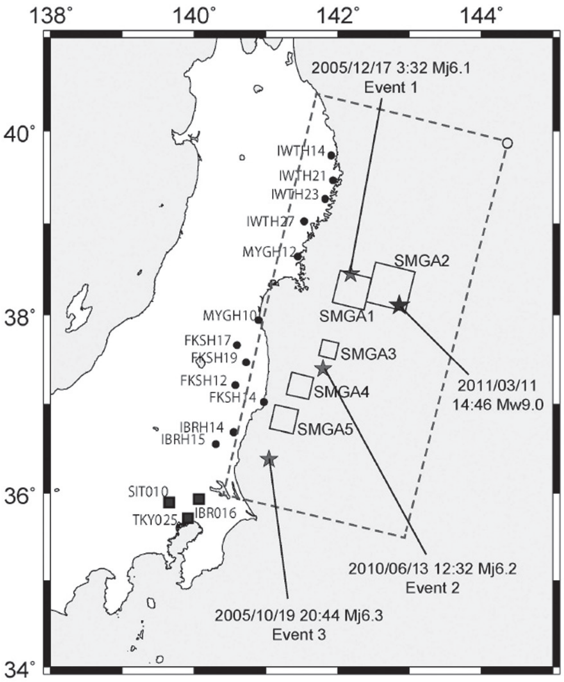

Figure 5 Source model for the 2011 Tohoku earthquake (locations and size of the five SMGAs)

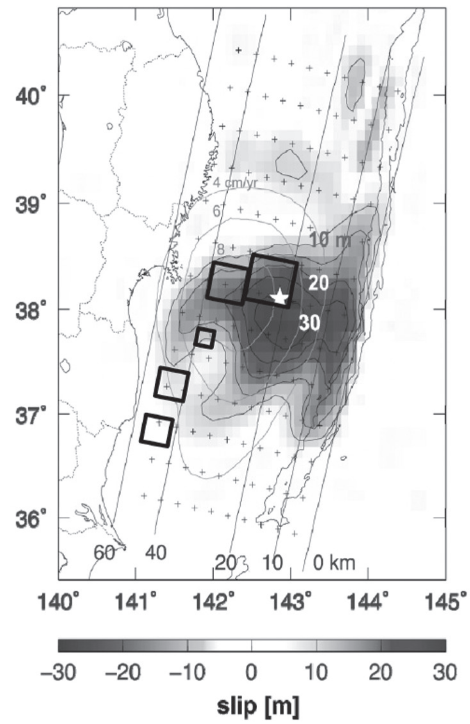

Figure 6 Comparison of the source model (slip distribution) from tsunami data and SMGAs (enclosed in five rectangles)

records, a comparison of ground motion characteristics could be made using the empirical characteristics of past earthquakes (e.g., the attenuation characteristics of maximum amplitudes). In the resulting report, the seismic ground motion was sufficiently within the predictable range taking into consideration the extent of the source zone and the inhomogeneous rupture process, although the magnitude of Mw 9.0 was admittedly beyond the scope of the empirical formula [5)]. As described earlier, another report suggests that the assignment of plural simple SMGAs enables the reproduction of a seismic ground motion from 0.1 to 10 seconds, which is the most critical time range in terms of engineering. Moreover, the locations of the respective SMGAs (i.e., the ones off the coast of Miyagi, Fukushima, and Ibaraki) proved almost consistent with the source zones of the interplate earthquakes postulated for the three target sites in seismic backchecks (i.e., the Onagawa Nuclear Power Plant, the Fukushima Daiichi and Daini Nuclear Power Plants, and the Tokai Daini Nuclear Power Plant) (**Figure 7**). The report pointed out that the peak amplitudes of the assessed design basis seismic ground motions did not differ greatly from the observation results. An important task for the future is to consider how any new findings and the identified challenges should be applied under the new regulatory standards for earthquakes and tsunamis to postulate earthquakes for investigation (interplate earthquakes) and to model their sources as well as to estimate the design basis seismic ground motions.

In this figure, the source zones for the linked Miyagi offshore earthquake are postulated for the Onagawa Nuclear Power Plant, the hypothetical Shioyazaki earthquake for the Fukushima Daiichi and Daini Nuclear Power Plants, and the 1896 Kashima Sea earthquake for the Tokai Daini Nuclear Power Plant.

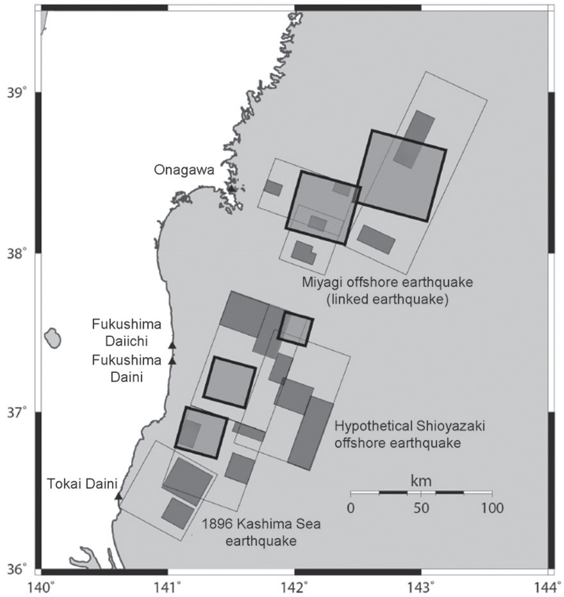

Figure 7 Comparison between the postulated source zone (model) for the interplate earthquake at three nuclear power plants on the Pacific coast (i.e., the Onagawa Nuclear Power Plant, the Fukushima Daiichi and Daini Nuclear Power Plants, and the Tokai Daini Nuclear Power Plant) and the source model for the 2011 Tohoku earthquake with five SMGAs (◻).

IV. Conclusions

This commentary provides a brief explanation of the evolution of assessments of design basis seismic ground motions, which greatly influence the seismic safety of nuclear power plants. More specifically, it describes how the original Seismic Guide was established in 1981, how it was revised in 2006 by incorporating new findings, and how it evolved into the new regulatory standards for earthquakes and tsunamis. Advancements in seismology, earthquake engineering, and other relevant fields combined with the data accumulated from earthquake observations have made it possible to predict the seismic ground motions of future earthquakes scientifically. Such predictions have also been employed in the assignment of design basis seismic ground motions. These prediction methods have arguably been advanced by their application to nuclear facilities. Nonetheless, uncertainty concerning seismic sources remains an important factor, particularly in evaluating those earthquakes that have a seismic source located near the target site. The assessment of residual risks as required under the Revised Seismic Guide (2006) should be conducted by not only referencing the exceedance probabilities of design basis seismic ground motions, but also taking into consideration the fragility of the facilities and equipment, the accident sequences, and other overall risks as well as by minimizing such risks through the necessary efforts and measures. As a result, I believe that it is possible to respond to an earthquake that exceeds the postulated scale, such as the 2011 Tohoku earthquake.

The assignment of seismic ground motions as the design basis is extremely important, and it must be based on scientific evidence. Nonetheless, the seismic safety of nuclear power plants can be continuously enhanced by accepting that stronger ground motions than those assigned can take place. Given this, residual risks must be assessed more specifically according to the requirements that have been carried over from the Revised Seismic Guide (2006) to the new regulatory standards for earthquakes and tsunamis. As the importance of safety margins was demonstrated by the 2007 Chuetsu offshore earthquake, safety margins must be further enhanced with regard to the vulnerability of facilities identified in recent stress tests, thereby continuing to improve the seismic safety of nuclear power plants. Any requirement for excessively stronger design basis seismic ground motions without sufficient scientific evidence only obstructs the positive thinking of engineers and does not enhance safety. Meanwhile, the new regulatory standards for earthquakes and tsunamis require the absence of faults and other outcrops that may trigger seismic activity just below important facilities. Without a doubt, it is still difficult for today's science to provide precise predictions of ground surface displacements (permanent) mainly caused by faulting. Risk assessments should arguably be based on the findings available at present and the extensive future use of current technologies to consider the way each displacement occurs and its past history (survey results), rather than by treating possible faulting and other seismic movements as the same. Such efforts can be expected to result in the development of new technologies.

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Commentary

Earthquake and Seismogenic Fault, and What is the Active Fault

−Eliminate a Delusion and Rumor for Active Fault and Give a Calm Response−

Tokyo Metropolitan University, **Haruo Yamazaki**

In an investigation of the Tachikawa Fault, which is a major active fault in the western suburbs of Tokyo, an artificial object was mistaken for a fault fracture zone. This commentary discusses the cause of this error and points out that misunderstandings and incorrect assumptions must have been made regarding matters such as the patterns of surface ruptures that appear during a major earthquake. To avoid such misunderstandings, the commentary explains surface ruptures and active faults as consequences of their repetition. The prevention of disasters arising from active faults, which can trigger major earthquakes, would require us to predict the behavior of surface ruptures, which is prone to misunderstandings and incorrect assumptions due to insufficient knowledge and other factors. The dangers of such misunderstandings must be kept in mind to ensure that active faults and other hazards are dealt with calmly.

I. Incorrect Assumptions in an Investigation of an Active Fault

In its trench excavation investigation on the Tachikawa Fault, which is an active fault in the western suburbs of Tokyo, the Earthquake Research Institute (ERI) of the University of Tokyo mistook an artificial object that was probably made of cement for a fault fracture zone, which is usually formed by rocks being ground in repeated fault slips. In February 2013, the ERI provided a misleading explanation to nearly 10,000 citizens and the press when the site was displayed to the public. This incident had become big news by the end of March. The lead researcher for the investigation explained at a press conference that their incorrect assumptions had led them to mistake an artificial object for a fault fracture zone. This may well have been the case, but the issue that still needs to be addressed is how cement could have been mistaken for a fault fracture zone. The answer could be easily found in the documentary film “Megaquake,” which was aired in an evening broadcast by NHK on April 7. The program showed a few people observing the supposed fault fracture zone in the exploratory trench. After that, a very brief narration announced that the site had been mistaken for a fault

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before cutting to the next scene. However, a later explanation of a computer graphics (CG) of the fault activity there was astounding. This CG showed a surface rupture running like a bolt of lightning from a vast empty plot with a close resemblance to the site of the trench excavation investigation toward a city similar to Tachikawa that had a monorail. In the aired simulation, a vertical displacement emerged across roads in the city and the columns supporting the monorail collapsed. Apparently, the producer of the program had prepared the computer-generated simulation based on the survey findings explained by the ERI. When this explanation subsequently proved to be incorrect, the inconsistent part of the explanation was simply cut and the simulation was still aired. However, the incorrect assumption that led to this serious mistake was still there.

The Tachikawa Fault vertically displaces a vast alluvial fan that used to extend along the river banks of Tama River during the ice age that occurred about 20,000 years ago (the fan dried up to form the Tachikawa Terrace). This fan is composed of a thick (over 40 m) poorly lithified gravel layer. A displacement involving a fault situated in deep lithified sandy and muddy sediments is dispersed in the thick gravel layer above them. The surface strata (gravel) are gently distorted without any slippage or vertical displacement. A gentle distortion with no discontinuity in the strata is called a "flexure." For this reason, there are no escarpments along the Tachikawa Fault. Instead, gentle slopes are ubiquitous. The first paper [1)] that described the Tachikawa Fault has already mentioned flexure as its most striking feature.

In other words, fault movements underneath the Tachikawa Terrace do not produce the type of dramatic vertical surface displacement that was depicted in the CG simulation. Such fault movements will just cause the existing gentle slopes to steepen slightly from the flexure of the gravel layer. Lacking a proper understanding of this flexure, the ERI team conducted an investigation based on the incorrect assumption that any fault movement would result in clear slippage (vertical displacement). They then found a convenient vertical structure, which was prematurely deemed a fracture zone. Conventionally, scientific investigations of active faults have relied on the inductive inference of their presence based on various types of geological data. For the findings to be applied in disaster management and forecasting, the magnitude of earthquakes and the amount of displacement resulting from active faults would need to be inferred deductively based on available knowledge. In the process of doing this, even so-called experts are prone to make misguided assumptions or presumptions due to insufficient knowledge or misunderstandings in relation to fault movements. The failure of the many experts involved in this investigation to identify their mistake is most likely due to such incorrect assumptions and shared presumptions.

II. Rumors about Active Faults

News and media commentary on active faults are clearly misguided as they breed rumors that incite fear and an unreasonable aversion to such faults. The most critical misunderstanding with respect to active faults is that devastating fault displacements will necessarily cause the total destruction of nearby structures. People will naturally fear faults after seeing footage of buildings being destroyed along a displacement. However, our experience of earthquake disasters demonstrates that major damage, particularly casualties, is not caused primarily by collapsed structures as a direct result of fault displacements. On the contrary, most damage is caused by the impact of tsunamis, the collapse of buildings that lack seismic resistance and are situated on soft ground, and the spread of fire. If we incite fear of the displacement of active faults, we will blind ourselves to the real causes of damage and even exacerbate them. In Tachikawa and other parts of the Musashino Upland that are on solid ground, the truly formidable hazard that requires prudent measures is the spread of fire in areas with increasingly dense clusters of wooden dwellings.

To dispel misconceptions and rumors regarding active faults, the only solution is to provide ample explanations of earthquakes and active faults to interested parties so that they understand the actual process involved in identifying active faults. With this in mind, this commentary describes phenomena that occur on the ground surface due to fault movements with the aim of clarifying the relationship between earthquakes and active faults.

III. Earthquakes and Faults

Regardless of its magnitude, an earthquake is triggered underground by a fault movement; in other words, it is caused by the relative slippage and displacement of rock on either side of the fracture surface of a fault. Given the shallow crust of the Japanese Islands, faults in this country are driven by the strain that builds up inside the continental crust as an additional gain from plate movements and other factors. Within a certain range, this strain will accumulate along a fault as a weak line in the crust. When a concentration of stress overwhelms the frictional strength of the fault plane, the rock on one side of the fault plane slips relative to that on the other side. This displacement produces a strong seismic ground motion. A deep underground fault that triggers an earthquake is called a “seismogenic fault.” In the inland part of the Japanese Islands, seismogenic fault movements occur only within a certain depth. Under the extremely high temperature that exists over 20 km beneath the Japanese Islands, the rock is too ductile to build up any strain. Furthermore, the rock situated about 3 km below the surface is too fragile to accumulate strain. For this reason, strain builds up and causes seismogenic fault movements in areas with hard rock within the range of 3 to 20 km underground. This part of the crust is called a “seismogenic layer.”

There are many weak lines in a seismogenic layer, and fault movements in these layers are triggered in the most brittle parts according to the direction of stress and the strength of the fault planes. The amount of energy generated by an earthquake triggered by a fault slip is expressed in seismic moment (Mo; unit: N·m). There is a known relationship of $Mo = \mu AD$ [2], wherein μ denotes the modulus of rigidity (Pa), D represents the amount of displacement along the fault plane (m), and A denotes the area of the fault (m^2). For intraplate earthquakes without a sizeable difference in μ, the magnitude (M) of an earthquake triggered by a fault depends on the area and displacement of the fault. The parameter A is a product of the horizontal length L of the fault and the width W along the depth direction. Since the thickness of a seismogenic layer is limited to about 17 km, M depends on the fault length L and the displacement D as the fault grows bigger. In an earthquake with a high value for M, the value grows in proportion to the fault length as the scaling law applies between D and L; in other words, a long fault is likely to cause an earthquake with a large magnitude. **Figure 1** shows the relationship between the fault length and the magnitude in a cross section of the shallow continental crust of the Japanese archipelago. It also shows the magnitude at which a surface rupture emerges. An earthquake with a low value for M is triggered by a short seismogenic fault with a small displacement. The impact is felt only in the seismogenic layer without a visible fault slip appearing on the surface. In contrast, if the value for M is seven or greater, the seismogenic fault slips across the seismogenic layer and penetrates the upper boundary. A

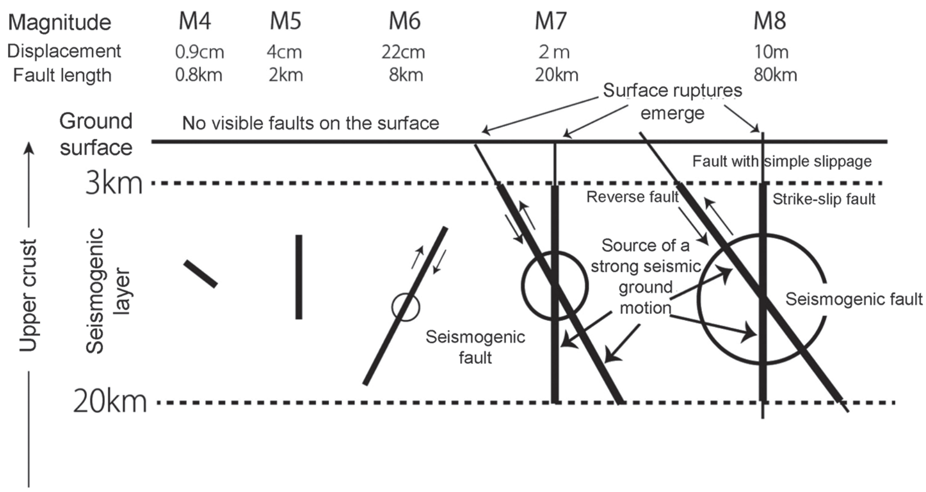

Figure 1 Relationship between a seismogenic layer and the presence of seismogenic faults and surface ruptures

fault that appears on the ground surface is called a "surface rupture."

Surface ruptures are an extension of seismogenic faults located under the ground surface. Their orientation and the amount of displacement are believed to provide important clues to understanding the nature of seismogenic faults located deep underground. Whenever faults appear due to a major earthquake, researchers record their details [3, 4]. The faults that appear on the ground surface are not limited to master faults as a direct extension of the seismogenic faults. Spray faults also appear when a fault extends upward before branching out in a relatively brittle layer near the surface. A small secondary fault may appear if a fault that is not directly connected to a master fault slips as a result of a seismic ground motion or the like (**Figure 2**). Even if a detailed investigation is conducted after an earthquake, only master faults that exhibit a large displacement can be identified because it is difficult to distinguish smaller faults based on the source mechanism. Given this, unless they are clearly formed by the action of gravity on the surface, all faults are called surface ruptures with assumed structural origins. In other words, faults that appear on the ground surface are formed by many different factors.

Sometimes, secondary faults may appear on the ground surface due to ground consolidation, liquefaction, and landslides being induced by the tremors. Faults associated with landslides and the like are not classified as surface ruptures. As is the case with the Tachikawa Fault mentioned earlier, some conditions on the surface only result in flexural deformations or open cracks instead of visible master faults. For instance, the 1948 Fukui earthquake (M 7.1) was caused by a fault movement underneath a plane lying on thick alluvium. On the ground surface, only an extensive strip of irregular cracks was observed. However, a survey conducted after the earthquake confirmed that, within the range of a few kilometers, the ground had been displaced by 70 cm vertically and about 2 m horizontally [5]. Most probably, the thick soft ground there led to invisible extensive flexure instead of ground ruptures.

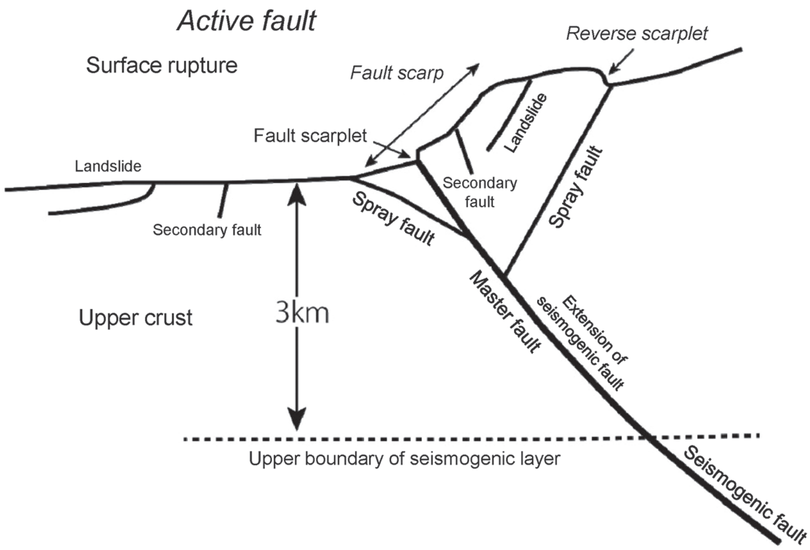

Figure 2 Various types of surface ruptures
Master faults shape the fault topography. There are also relatively large spray faults and small secondary faults. Some faults emerge due to landslides and other kinds of gravitational action on the surface.

IV. Repeated Surface Ruptures and Active Faults

The huge movements of seismogenic faults that produce surface ruptures are believed to repeat in a cycle of over 1,000 years as they slowly accumulate strain during dormant periods before overwhelming the frictional strength to cause a fault displacement almost instantaneously (i.e., after a few dozen seconds). This belief is based on the concept that a fault will cause an earthquake of a similar magnitude at a constant interval provided no major changes occur in relation to the strain rate of the crust over time and the friction strength remains relatively stable.

Once surface ruptures emerge due to fault movements, they are eroded and buried by sedimentation. Small displacements and gaps tend to disappear over the long dormant period that follows. The scarplets of master faults and other faults with a sizeable displacement leave until their next period of activity. In the next period of activity, new slips are added to enlarge the land features and geological displacements. As a result, master faults gradually form large scarps or other distinctly discontinuous geological gaps. This type of distinct landscape that forms on the surface due to repeated fault movements is called “fault topography.”

The Great Hanshin Earthquake that devastated Kobe in 1995 formed a surface rupture that extended about 10 km on the northwestern part of Awaji Island. This rupture forms part of the southwestern extension of the seismogenic fault from underneath the foot of Mt. Rokko, which is situated near Kobe City. This fault, known as the Nojima Fault, was active even before the earthquake. As indicated on the map shown in **Figure 3** (a), the surface rupture emerged on Awaji Island along the northwest coast to form an upheaval on the eastern side of up to 1.2 m and a dextral strike-slip of up to 2.5 m. This surface rupture runs straight along the foot of the steep slope that marks the northwestern border of Tsuna Hills on the northern part of the island (Figure 3 (b)). At the point where the rupture emerges, a fault fracture zone can be observed between the granite on the east side and the bordering Osaka Group on the

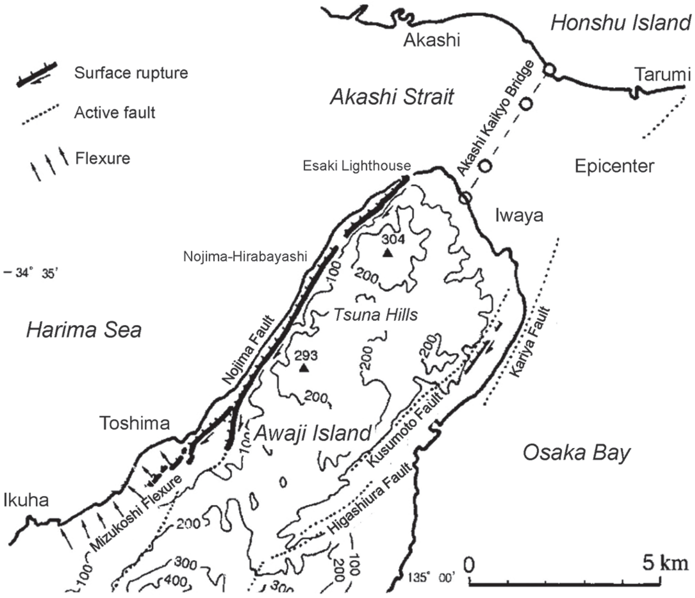

Figure 3 (a) Surface rupture that emerged along the northwestern coast of Awaji Island due to the Great Hanshin Earthquake in 1995
The Nojima Fault, which is known to have existed since before the earthquake, resumed its activity (Haruo Yamazaki, 1998) [6].

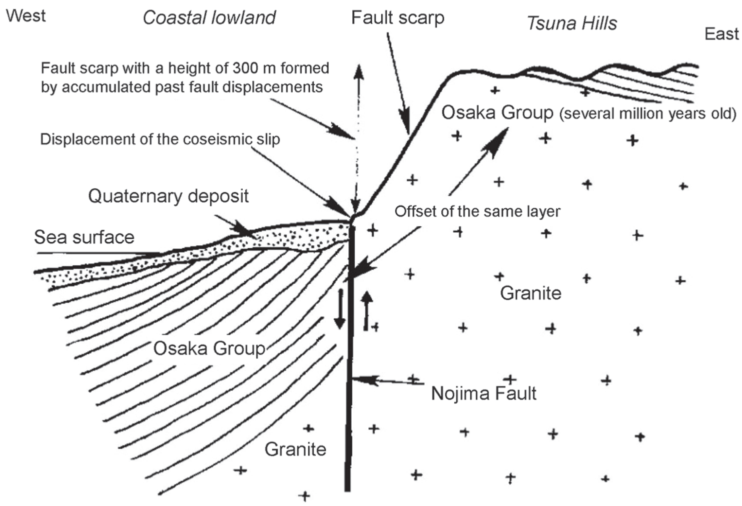

Figure 3 (b) East-west cross-section of the northern part of Awaji Island
The point at which the surface rupture emerged coincided with the foot of a large fault scarp.

west side. This zone indicates that the earthquake was generated by the resumed activity of a fault with a long history. On top of Tsuna Hills, which is formed of granite and located on the east side, the Osaka Group extends just as it does on the west side. The difference in height between these two sides amounts to 500 m. This difference is a result of repeated fault activities in the geological period after the Pliocene. The steep slope that runs along the rupture was probably formed by fault movements. Put another way, faults that have formed fault scarps and the like due to their repeated activity in recent geological times are likely to continue to exhibit the same activity unless they experience any dramatic changes. Faults that may cause major earthquakes in any future activity were named “active faults” by Fumio Tada [7]. In other words, faults that are geologically proven to have exhibited repeated activity in recent geological periods to form fault topography can be considered active faults with the potential to trigger major earthquakes in any future activity.

Worryingly, the recent use of terms such as “surface ruptures” and “active faults” seems to be increasingly diverging from the original concepts as explained in this commentary. As an example, let’s consider the earthquake with an intensity of 6 lower on the Japanese scale (M 6.3) that struck Awaji Island early in the morning on April 13, 2013. The press repeatedly stated, “An unknown active fault has moved.” Active faults are, by definition, visible on the ground surface. Around the epicenter of this particular earthquake, no active faults have been identified. Furthermore, none of the area’s geological features or structures have the potential to be active faults. The earthquake had a high magnitude, but the displacement was limited to within the seismogenic layer. This displacement failed to reach the surface during this earthquake or any preceding ones. The media coverage confused a seismogenic fault with an active fault. The fault slips from small earthquakes that take place every day remain within the seismogenic layer. They are movements of completely unknown faults. The misguided association of such earthquakes with active faults may come from a subconscious desire to attract attention to the news by capitalizing on the current talk that “active faults are dangerous.”

As this demonstrates, terms such as “active faults” and “surface ruptures” are frequently used in a way that is inconsistent with their original definitions or as idiomatic expressions. Having become mixed up with misunderstandings and misguided assumptions, these terms could breed or spread confusing rumors. We hope that this commentary will help dispel such rumors and facilitate a calm response to the hazards posed by active faults and surface ruptures.

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Commentary

Risk Concept for Nuclear Safety Assurance after Fukushima Accident

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This commentary highlights the importance of risk concept in ensuring nuclear safety in the wake of the Fukushima Accident. A new risk concept is presented and then the issues and outlook for ongoing safety regulations are discussed as tangible embodiments of risk concept. The commentary goes on to describe a new concept that has been expanded from the classic concept of risks, whose importance was recognized after the accident at the Fukushima station and is arguably the most important lesson learned. Finally, the commentary also touches upon the issue of safety regulations as a practical embodiment of the theory to stress the importance of the following: regulatory reform based on risk concept, communication and partnerships among stakeholders, and more effective accountability for safety regulations.

I. Introduction

Two and half years on from the Fukushima Accident, a path toward the treatment of contaminated water and the decommissioning at the Fukushima Daiichi Nuclear Power Station has not yet been identified. Over 100,000 evacuees from Fukushima need supportive care and a mountain of serious challenges have yet to be overcome. Meanwhile, nuclear power stations in Japan are being examined toward the restart by ensuring their conformity with the new regulatory standards, based on lessons learned from the Fukushima Accident and established by the Nuclear Regulatory Authority (NRA) last year.

The valuable opinions and commentaries provided by colleagues in the monthly ATOMOΣ (Journal of the Atomic Energy Society of Japan) have been very helpful for an engineer like the author to clear his thoughts and discover new perspectives. Thanks to such insights, various important issues are becoming clearer. With a background in structural engineering, the author has long been involved in various aspects of nuclear seismic safety, such as the seismic design of nuclear facilities and the development of methods for conducting a seismic probabilistic risk assessment (PRA).

The author specializes in the assessment of structural reliability and risks. The research that he engages in extends to uncertainty analysis, which considers factors such as various types of uncertainties, variability, and imperfect knowledge. Recently risk management in

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general is also an area of interest for the author. In essence, the PRAs conducted at nuclear power stations involve the type of formulation and embodiment of risk management that we carry out in a broad sense either consciously or unconsciously when making various decisions.

Based on such author's experience, this commentary discusses the importance and expected roles of the risk concept from the view point of ensuring safety and safety regulation of nuclear power stations.

II. Importance of the Risk Concept

1. Uncertainties and Risks

As one of the lessons learned from the accident at the Fukushima Daiichi Nuclear Power Station, the importance of both the recognition of uncertainties and the risk concept has been pointed out in a report for the IAEA ministerial conference and by many experts [1-3]. Any assessment of earthquakes and tsunamis as natural phenomena entails a large number of uncertainties. Earthquakes involve not only temporal and spatial uncertainties (when and where they take place), but also uncertainties concerning their characteristics (earthquake magnitude). Uncertainties concerning the propagation of seismic waves and tsunami waves from their sources to power stations cannot be ignored. In the structural engineering community, the following quote has often been applied with respect to manufacturing under an uncertain environment [4].

Structural engineering is the art of molding materials we do not really understand, into shapes we cannot really analyze, so as to withstand forces we cannot really assess, in such a way that the public does not really suspect.

The key points in this definition of structural engineering are the recognition and measurement of uncertainties concerning materials, external forces, and analysis models and the provision of an appropriate accountability to the public about adequate decisions made under uncertain environments. This principle can be applied directly to nuclear power stations during their design and assessment.

Structural safety remains an issue because of ever-present uncertainties. So, how should uncertainties be measured? Probability theory is commonly employed to recognize and measure uncertainties. A probabilistic model can be constructed for future events or phenomena controlled by chance with a certain degree of accuracy based on statistical data, experience, and knowledge from the past. The safety of a structure involving many types of uncertainties needs to be assessed by considering the probabilities of the hazards that apply to the structure and the degree to which the surrounding environment will be affected. Consequently, the risk concept plays an essential role.

The International Organization for Standardization (ISO) [5] defines risk as "a combination of the consequences of an event and the associated likelihood of occurrence." Here, this combination refers to either the product of these two elements (expected damage) or a risk curve that expresses the probability and degree of consequence together.

Many methods can be used to reduce risks associated with the safety of structures that are subject to natural phenomena. In addition to building a more robust structure (to reduce the failure probability), it is also possible to mitigate the damage (impact) that may be caused if the structure collapses. These approaches are respectively referred to as "prevention" and "mitigation." The relative feasibility and effectiveness of these two approaches are diversified depending on the intended targets. In terms of saving lives as a target, if we consider the damages caused by earthquake and tsunami, for instance, both approaches are viable for mitigating any damage involving seismic risks. In most cases of tsunami risk mitigation, however, it is more effective to improve alerts and evacuation measures than it is to build robust embankments.

The comparison of risks associated with different types of causes is also an effective option. **Figure 1** compares risk curves for the number of people killed by earthquakes, typhoons, heavy rain, snow disasters, lightning strikes, and volcanic eruptions based on disaster statistics for Japan. The horizontal axis represents the number of people killed by the respective cause, while the vertical axis represents the annual frequency of the relevant event. This comparison demonstrates that annual deaths of around 10 people are most often caused by typhoons. Although they are infrequent, earthquakes and volcanic eruptions kill a large number of people. These risk curves help us understand the characteristics and frequencies of such disasters. In this manner, risk curves can be drawn based on past statistical data. If little data is available, a curve can be estimated by conducting risk analysis.

Comparisons based on the nature of the damage caused are also effective. An examination of the causes of death from past earthquakes demonstrates that people lose their lives in completely different ways. A little less than 90% of the deaths that occurred in the 1923 Great Kanto Earthquake were caused by fire. In contrast, over 80% of the deaths that occurred early in the morning in the Great Hanshin Earthquake were caused by people being crushed under collapsed buildings. Over 90% of the deaths that occurred in the 2011 Great East Japan Earthquake were caused by drowning due to the major tsunami that the earthquake triggered. Simply providing a strong structure is, therefore, inadequate. Multifaceted measures must be devised according to the nature of the damage caused.

In light of this, risk management applies the risk concept to achieve a target performance for a target system by selecting and implementing optimal measures from among various options for reducing risks. A higher degree of safety can be achieved for the overall system by feeding back the assessment results and using them to consider introducing multiplicity aimed

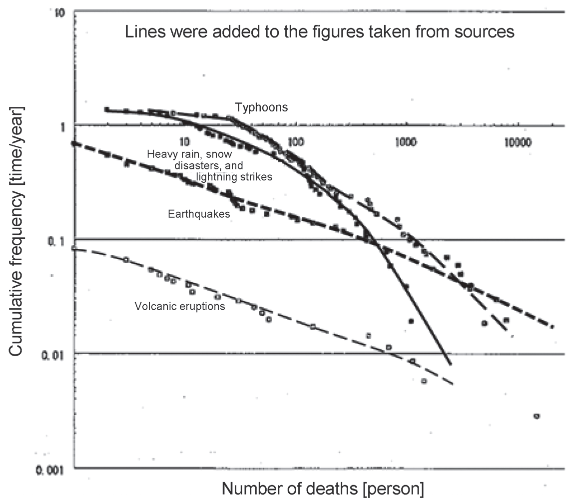

Figure 1 Comparison of risk curves for natural disasters in Japan [6)]

at ensuring safety during an emergency. As the accident that occurred at the Fukushima Daiichi Station demonstrates, past accidents involve factors from a wide range of areas. The risk concept is useful for ensuring that factors across this wide range of areas are handled consistently.

2. Concernment on Risks

(1) Misguided prioritization of the complete elimination of unexpected events

People tend to communicate in an emotional and subjective way after they have experienced a catastrophe like the Great East Japan Earthquake. They may say, for example, “we need to eliminate the unexpected” or “we need to build an absolutely safe zero-risk society.” However, going against nature to eliminate the unexpected is not easy. Rarely experienced events entail greater uncertainties, so we should acknowledge that it is impossible to avoid the unexpected events. Humankind may dream of achieving an absolutely safe zero-risk society, but such a society is not easy to build. Our role as engineers is to look squarely and objectively at this stark reality to seek realistic and feasible solutions while keeping in mind the uncertainties that are inherent to nature. Absolute safety cannot be achieved since uncertainties are always with us. Our emotional desire to expect or assume absolute safety for a particular target may actually endanger us, because lazy thinking based on a blind assumption of absolute safety will discourage us from pursuing the necessary disaster prevention and preparedness measures. The Fukushima Accident was arguably caused by such a mindset.

(2) Confusion of safety for peace of mind

The words “safety” and “peace of mind” do not reflect the same concept even though they are often used interchangeably[7)]. The word “safety” concerns objective and scientific issues, while the word “peace of mind” concerns subjective and psychological issues. A stronger building can provide safety, but it does not necessarily provide peace of mind. Safety is just one element of peace of mind, which is dependent on a wide variety of conditions, such as a sense of trust and the provision of satisfactory explanations. Therefore, it should be noted that measures for enhancing safety are not necessarily identical to activities that can build a sense of peace of mind.

Figure 2 illustrates the concepts of safety and peace of mind based on a reference document[7)]. The figure provides a two-dimensional representation of a target with axes that have scales ranging from safe to dangerous and from peace of mind to anxiety, where anxiety is a desirable reaction to something dangerous and peace of mind is a desirable condition if something is safe. Mistakenly feeling reassured by something dangerous, as shown in Domain A, is obviously undesirable. Similarly, it is problematic if people cannot feel reassured by

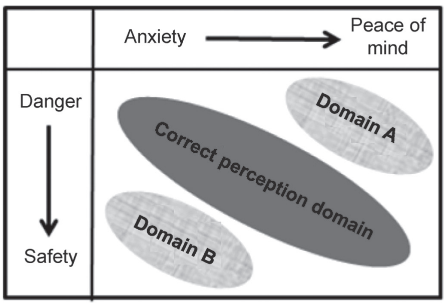

Figure 2 Domains of safety and peace of mind

something safe, as shown in Domain B. Many people point out the importance of issues concerning risk communication in dealing with such psychological matters. Indeed, risk communication between the public and experts as well as among experts from different fields is an extremely deep-seated issue.

Although these issues belong to the domain of risk psychology, attention must be paid to them in order to avoid common mistakes that can even be observed among experts who confuse safety and peace of mind in their discussions and logical reasoning. All too often, subjective emotional expressions are used in reasoning, thereby hampering scientific and logical discussions among specialists. The most desirable approach is to make a conscious distinction between objective matters and emotional subjective matters.

III. Emergence of a New Risk Concept

1. Safety Burst

The devastation that followed in the wake of the tsunami triggered by the Great East Japan Earthquake and the resultant accidents at the nuclear power stations in Fukushima taught us the lesson that the conventional risk concept must be expanded along the time and space axes [8]. The author and his colleagues from a working group at the Engineering Academy of Japan explored a forthcoming risk concept to point out the following two characteristics [9].

(1) Simultaneous occurrence

(2) Cascading disaster

The concept of simultaneous occurrence is similar to that of common cause failures. Resulting from a simultaneous failure or destruction of multiple systems in different regions of space, it may have a common cause or independent causes. This is an extension of the risk concept along the space axis. As demonstrated at the power stations in Fukushima, cascading disasters involve changes in risks over time according to the changing conditions at the stations, which may compound the resultant damage. This is an extension of the risk concept along the time axis.

The working group [9] proposed the new concept of a “safety burst,” which is defined as a failure to maintain and ensure the intended performance of a potentially influential system in an escalating chain reaction triggered by damage in a single spot or simultaneous damage in multiple spots. The devastation caused by the recent major tsunami and the subsequent accidents at the power stations are considered something close to a safety burst in that an external disturbance led something supposedly safe to develop into an unexpected condition. A safety burst, therefore, highlights the need to expand the conventional risk concept to consider situations that are beyond our current knowledge or imagination.

2. Characteristics of Modern Systems

Figure 3 has been extracted from a reference [9] to explain the characteristics of modern engineering systems by comparing the nature of damage in the past and the present. The following observations can be made.

(1) The risks posed by the failure of more advanced technologies tend to increase, compared with the past, leading us to a contradictory position in which more advanced technologies actually pose greater danger.

(2) Safety-related information makes us belittle dangers and discourages us from pursuing

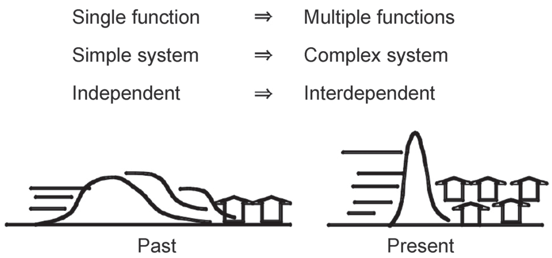

Figure 3 Differing nature of damage in the past and the present [3)]

intellectual efforts to prepare against dangers.

Risk management must incorporate a new concept for dealing with the new, unprecedented risks associated with more multiple-functioned, more complex, and more interdependent engineering systems.

3. New Concepts

Various new concepts are being proposed to deal with the abovementioned emerging risks while reflecting the characteristics of modern engineering systems. These concepts include robustness, self-sustainedness, dynamic risk management, and resilience, which can be explained as follows.

Robustness: The robustness of structures that have been designed and built by eliminating weak spots (Achilles' heel) to be insensitive to even small external disturbances.

Self-sustainedness: Not limited to engineering systems but modern society in general largely depend on infrastructure to supply power, gas, water, information, and so on. The functional loss of any such infrastructure can paralyze multiple systems. Self-sustainedness (also known as "autonomous decentralization") is needed to compensate for this weakness by configuring individual systems to depend as little as possible on other systems.

Dynamic risk management: Earthquake and fire risks, for example, are being assessed using structural systems in various organizations. A framework for risk management must be built to allow decisions to be made based on information that is as realistic as possible by pursuing risk assessments that incorporate the progression of damage that an earthquake causes to a structural system over time and any other real-time data that is available when the damage is sustained.

Resilience: Resilience is the capacity of a system to adapt to an external disturbance and retain its normal condition [10)]. A highly resilient system can be restored to its normal condition after experiencing a brief functional decline. This idea is similar to an extension of the risk concept along the time axis.

IV. Application of Risk Concept to Nuclear Safety

1. Risk Concept in Nuclear Regulation

Given the importance of the risk concept as explained earlier in this commentary, this section discusses the various issues involved in ensuring nuclear safety.

The concept of residual risk was introduced in the 2006 revision of the review guidelines for the seismic design of nuclear facilities by acknowledging this considerable uncertainty in future assessments of seismic ground motions. This development marked a dramatic breakaway from the myth of the absolute safety of nuclear power stations. It also marked the beginning of risk-oriented nuclear regulation. The following year, it became necessary to revise the design basis seismic ground motion Ss when the recorded ground motion intensity of the Niigata Chuetsu Offshore Earthquake at TEPCO's Kashiwazaki-Kariwa Nuclear Power Station exceeded the design basis seismic ground motion S2. In response, addressing the issue that a seismic ground motion exceeding the design basis had been recorded was made the top priority. The assessment of the residual risk was conducted only by referring to the exceedance probability of the ground motion Ss. This situation has not changed in the latest regulatory standards.

Unfortunately, the risk concept has not been proactively applied in the regulatory standards that the NRA established and put into practice for protecting commercial nuclear reactor facilities against earthquakes and tsunamis. This certainly represents a failure to break away from the ideological obsession with absolute safety despite the experience gained from the Fukushima Accident. The Great East Japan Earthquake attracted more scientific attention than ever before to the possibility of compounded major earthquakes and the uncertainties involved in the assessment of seismic ground motions. In pursuit of absolute safety, the seismic safety of existing nuclear facilities tends to be evaluated under extremely stringent conditions and extremely conservative and intense seismic ground motions. However, the imposition of such stringent conditions leaves the concern that they are still inadequate in ensuring the safety of nuclear power stations. This contradiction results from the ideological obsession with absolute safety; in other words, nothing is satisfactory until absolute safety is achieved.

In contrast, safety regulations based on the risk concept quantitatively gauge how safe nuclear power stations are rather than just asking whether they are safe or not. In other words, the requirement for ensuring safety is to clear socially acceptable criteria or safety goals that are separately defined. Various measures are taken to bring any existing risks below a certain threshold after assessing the residual risk. The important task here is to communicate to the society the fact that nuclear power stations are not absolutely safe and that they bear certain risks even though they deliver electric power as a benefit. Any party that neglects to pursue constant efforts to reduce even tiny risks should not be entitled to operate a nuclear power station.

The Fukushima Accident prompted a comprehensive safety assessment (or "stress test") of the behavior of each power station as a complete system by examining not only its highly important parts, but also other ordinary parts. More specifically, the behavior of each power station was comprehensively examined to identify weak points, avoid cliff edge effects, and assess the safety of seismic designs and measures against tsunamis. The assessment of a power station as a whole enhances its robustness by identifying vulnerabilities and ensuring the redundancy, independence, multiplicity and diversity of its safety systems. The installation of additional power supplies and other related activities achieved greater self-sustainedness and resilience for power stations.

Such a comprehensive assessment of the whole power station is essential if we are to gain a total-system perspective [11)], which is essential in ascertaining the entirety of the simultaneous impact that an earthquake and tsunami may have on the station site. It is also important to implement measures for dealing with severe accidents at nuclear power stations, which is essentially dynamic risk management aimed at dealing with the progression of emergencies over time.

2. Necessary Partnerships among Stakeholders in Nuclear Safety (from Confrontation toward Partnership)

Figure 4 presents possible interactions among the various stakeholders in nuclear safety. The Atomic Energy Society of Japan (AESJ) and other specialized academic societies also play important roles as groups of stakeholders. These parties were added to the figure to facilitate the identification of the problems faced by society. The author decided on his own views to represent the direction of each interaction with an arrow and the level of influence by the thickness of the line.

The four groups in the figure are expected to avoid confrontation and fulfill their due functions with the aim of achieving their common goals. The author hopes that this will allow society as a whole to handle issues related to nuclear safety properly. It is important to pursue cooperation and partnership among stakeholders, rather than conflict and confrontation.

Utilities and regulators interact closely through frequent plant reviews conducted to assess the possibility of restarting the power stations that are currently shut down. Utilities and regulatory authorities are inevitably in conflict over many issues related to nuclear safety. However, as long as safety remains a common concern, they should be discussing the extent to which safety needs to be ensured instead of engaging in dualistic discussions to decide whether power stations are safe or not. The risk concept is obviously essential in such quantitative discussions.

The Fukushima Accident has given rise to a widespread public perception that nuclear power stations pose terrifying problems that are beyond human control. Nuclear energy can never be promoted by ignoring the national sentiment and public opinion. An important task that we face today is to gain an understanding among evacuees from Fukushima, residents living near power stations, and Japanese citizens in general regarding nuclear safety and appropriate measures being taken to ensure safety. Utilities, regulatory authorities, and academic societies must adopt a suitable approach to gain support from the majority of the public, who have never been more vocal. As indicated in Figure 4, the regulatory committee meetings do not provide the public with adequate explanations of ongoing technical discussions, even though these meetings are conducted openly to ensure transparency. The same applies to academic societies and utilities.

The AESJ and many other academic societies play extremely important roles in enhancing nuclear safety because the operation of nuclear power stations depends on close partnerships

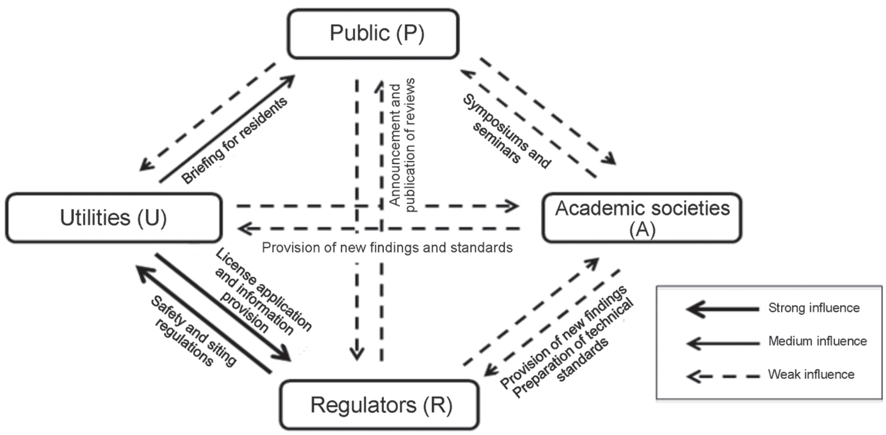

Figure 4 Interactions among stakeholders in nuclear safety

in many areas. Academic societies have a duty to provide scientific insights for regulators, utilities, and the public, including the fact that their intended targets always involve uncertainties. More importantly, academic societies must not only provide data for making decisions or selections, but also explain them in a clear manner to regulators, utilities, and the public.

Members of academic societies have different ideologies with respect to nuclear power. Some are dedicated adherents, while others are prudent skeptics. This diversity of views provides a healthy sign of academic societies that value freedom of thought. Scientific opinions based on different ideologies should be eagerly shared. Thorough discussions among people with different ideas are crucial if they are to acknowledge each other's different perspectives.

Some experts avoid discussions and collaborations with other experts that hold different ideologies, but this attitude is not advisable. It is important to remember that a genuine understanding of the different perspectives held by other experts can facilitate deeper, more broad-ranging analysis.

3. Issues Involving the Enforcement of Safety Regulations (Moving from Fairness, Openness, and Independence toward Providing Better Explanations)

Since July 2013, nuclear power stations throughout Japan that are currently idle have been examined to assess the possibility of them being brought back online by ensuring their conformity with new regulatory standards. The NRA is apparently determined to ensure that the nuclear accident is never repeated by lessons learned from the mistakes made in Fukushima. Based on earlier discussions, the author presents what is desired and expected from the enforcement of safety regulations.

First, the risk concept is essential for ensuring safety in the event of natural external accidents, such as earthquakes and tsunamis. In the United States, the Nuclear Regulatory Commission (NRC) [2)] has declared its pursuit of performance-based regulations that apply risk-oriented information effectively. Japan did introduce residual risk for the first time in its former guidelines, but it was applied only passively by referring to the results of a PRA of earthquakes in determining the design basis seismic ground motion Ss. It is advisable that more broad-ranging safety measures be carried out through the implementation of PRAs on earthquakes and the proactive application of the PRA standards for tsunamis that are being developed by the AESJ. This is possible precisely because the deterministic approach and probabilistic approach are complementary and do not conflict with each other. Basically, methodological diversity must be pursued to ensure safety.

Second, peer reviews and detailed on-site surveys (walkdowns) are necessary to address technical issues. In a peer review, materials based on assessments conducted by utilities are reviewed from a technical perspective by impartial engineers and experts. The main purpose of this is to ensure the integrity of the reviews. The review results are more reliable if they are checked by multiple persons. On-site surveys, which are already being carried out, are also extremely useful. These on-site walkdowns are conducted by experts from different backgrounds to obtain information that is not covered fully in their briefing materials and to gain a more realistic visualization of the conditions inside a power station during an earthquake.

Third, although regulators do place a suitable degree of importance on the fairness, independence, and openness of reviews in their interactions with stakeholders, as explained in section IV-2, the public must be given better explanations. Regulators review the materials submitted by utilities according to the relevant standards. Here, both sides need to clarify what the priority issues are for safety reviews. The public's confidence can be built up by, for example, clearly explaining what the utilities are doing to address these issues, how the technical issues fit the bigger picture, and what the logic is behind the possible solutions.

Attention should be drawn to another important point concerning better explanations. Scientific discussions should not be confused with engineering decision-making process. In any discussion, a clear distinction between the domain of science (the pursuit of truth) and the domain of engineering judgments (decision-making process and choices selection) can improve the quality of the explanation provided. Clarification on who makes decisions and how they are made can significantly enhance the quality of an explanation. Reviews must be purely technical in line with the declaration issued by Mr. Tanaka, the NRA Chairperson, that, “we are reviewing existing power stations with respect to their conformity to the new regulatory standards, but we are not authorizing any resumption of operations.” The authorization of any resumption of operations must be decided by the government based on the results of NRA reviews with due consideration given to social needs and the external environment.

V. Conclusions (toward Next Steps)

This commentary discusses how nuclear safety should be ensured following the Fukushima Accident. In particular, it describes the importance of the risk concept, the need to introduce a new concept, and the importance of partnerships among different stakeholders. Based on these considerations, the challenges and desirable approaches were presented for safety regulation. The safety of nuclear power stations as huge complex systems requires a more mature safety concept. To this end, it is essential for the risk concept to be understood and take root. Even risking criticism for pursuing this ideal in the face of the difficulties that would be encountered in reality, the author remains an ardent believer of the important role played by risk concept.

Heated discussions are underway over whether to bring nuclear power stations that are currently idle back online. For instance, it is necessary to clarify how experts should explain nuclear safety to other stakeholders and what kind of discussions should be held among the stakeholders. Indeed, the issues continue to mount. Nonetheless, the author believes that holding active discussions among the various stakeholders in the spirit of partnership can lead us to a breakthrough.

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Issues on Criticality Safety Control of Fuel Debris
−Preparation for the Decommissioning of Reactors at the Fukushima Daiichi Nuclear Power Plant−

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A technical review was conducted on resolving the issue of criticality safety management for fuel debris to ensure the proper decommissioning of the Fukushima Daiichi Nuclear Power Plant of the Tokyo Electric Power Company. In addition to conducting sufficient examination inside the reactors, consideration must also be given to reducing the overall risks while developing technologies and procedures for removing fuel debris.

I. Introduction

The Fukushima Daiichi Nuclear Power Plant of the Tokyo Electric Power Company (TEPCO) experienced a core meltdown in all of the three reactors (Units 1–3) that were in operation when an earthquake struck on March 11, 2011. Molten fuel debris is presumed to have not retained inside the pressure vessels, but to have spread inside the primary containment vessels. The Nuclear Emergency Response Headquarters developed Mid-and-Long-Term Roadmap to begin the removal of the fuel debris by the first half of 2020 and complete it within 10 to 15 years (the decommissioning is scheduled to be completed within 30 to 40 years).

There are many technical challenges involved in the removal of fuel debris, such as the criticality safety management technology for fuel debris. This technology monitors the condition of the fuel debris with the aim of maintaining and managing subcriticality at each stage of the decommissioning process to prevent the molten fuel from reaching criticality and thereby leading to the release of a significant amount of radioactive materials. Many studies have been conducted on criticality safety management technology for nuclear fuel materials since the early days of nuclear energy usage. The findings from these studies have been compiled and published in handbooks, standards, databases, and so on. Unfortunately, these studies assumed fuels under normal conditions (including various forms and properties of fuels in reprocessing) rather than the type of fuel debris found at the Fukushima Daiichi Plant. In addition, almost no information has been obtained with respect to the quantity, shape, composition and position of the fuel debris present in each pressure vessel or primary containment

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vessel (PCV). For these reasons, it is necessary to develop technologies for ensuring criticality safety for fuel debris in anticipation of a variety of different situations as well as conduct examinations inside the reactor buildings (R/Bs) and the PCVs.

Issues related to criticality safety management for fuel debris in the decommissioning plan for the Fukushima Daiichi Plant were discussed during the Summer Seminar on reactor physics in 2011 and the planning lecture given by the Reactor Physics Division during the 2013 Fall Meeting of the Atomic Energy Society of Japan [1-3]. Based on these discussions, this commentary explains issues related to critical safety for fuel debris.

II. Decommissioning

1. Conditions at the Fukushima Daiichi Nuclear Power Plant

On December 16, 2011, the Japanese government (Nuclear Emergency Response Headquarters) declared that a “cold shutdown state” had been achieved for the reactors at the Fukushima Daiichi Plant after technically ensuring that the on-site radiation dose could be kept sufficiently low even in the event of any problems [4]. Two years on, cooling by water injection is still being conducted. Meanwhile, examinations of the inside of the reactor buildings (R/Bs) are underway. However, the extent of damage suffered to the fuels has yet to be ascertained.

Any criticality assessment of fuel debris requires data on factors such as its composition, properties, and shape, but we need to make do with estimated data at present. Consequently, the assessment results are greatly influenced by how conservative the estimates are.

Based on TEPCO’s analysis and their plant data, the following fuel conditions are estimated for the respective reactors [5, 6].

Unit 1: Almost all of the molten fuel has dropped to the lower plenum of the reactor pressure vessel (RPV), leaving almost no fuel at the reactor core. Most of the fuel debris that has dropped to the lower plenum is believed to have further dropped to the pedestal of the PCV. Fuel debris triggers a core-concrete interaction, but the fuel debris is believed to remain inside the PCV as the interaction has been stopped by water injection cooling and the subsequent reduction of the decay heat. As of December 2013, the temperature at the bottom of the pressure vessel is being maintained at around 20°C owing to the injection of water through the feedwater system (2.5 m^3/h) and the core spray system (2.0 m^3/h). The water level of the dry well (D/W) is estimated to be around 2.8 m above the floor, and the suppression chamber (S/C) is estimated to be almost full with water.

Units 2 and 3: Some of the molten fuel is believed to have dropped to the lower plenum of the RPV or the pedestal of the PCV, while the rest is believed to remain in the reactor core. Presently (December 2013), the temperature at the bottom of the pressure vessel is being maintained at around 25°C owing to the injection of water through the feedwater system (1.9–2.0 m^3/h) and the core spray system (3.5 m^3/h). The water level of the D/W for Unit 2 is about 60 cm above the floor. The water level in the S/C is similar to that of the torus chamber. In Unit 3, the D/W water level is between 5.5 and 7.5 m above the floor, but the water level in the S/C is unknown.

2. Mid-and-Long-Term Roadmap

In December 2011, the Japanese government and TEPCO drew up Mid-and-Long-Term Roadmap for decommissioning of the Fukushima Daiichi Plant (revised in July 2012 and June 2013)[7]. **Figure 1** provides an outline of this Roadmap. The main objective of the decommissioning is to minimize the impact of radioactive materials for outside of the site and reduce the exposure to the pre-disaster level. To this end, the following goals were set in the Roadmap to ensure safety.

(1) Complete the decommissioning as soon as possible while maintaining safe conditions at the plant.

(2) Ensure safety beyond the site (reduce exposure on the public).

(3) Ensure safety at the site (reduce exposure on workers).

The Roadmap is divided into three phases. Phase 1 begins with the completion of Step 2[a] and ends with the removal of fuel from the spent fuel pool for the first Unit undertaken. This phase was completed in November 2013. Phase 2 corresponds to the period up to the removal of fuel debris from the first Unit undertaken. In this phase, the necessary research and development is initiated along with the repair work for the PCV, stagnant water treatment is completed, and research and development into dismantling the facility and treating and disposing waste is initiated (the initial completion target is 10 years after the completion of Step 2, but a revision to the roadmap shifted the target to the first half of 2020). Phase 3 is scheduled to last until the completion of the decommissioning. Removal of the fuel debris is to be completed within 20 to 25 years from the completion of Step 2, while the decommissioning is to be completed within 30 to 40 years.

The removal of fuel debris is supposed to be performed according to the following steps.

(a) Decontamination inside the reactor buildings (R/Bs)

(b) Repair of R/Bs and PCVs to terminate the water leakage as well as switch from cooling through the use of a large circulation loop to cooling through the use of a circulation loop inside each building and, ultimately, to cooling through the use of small circulation loops[b]

(c) Examination and sampling inside PCVs

(d) Filling with water and opening of the top covers for the pressure vessels

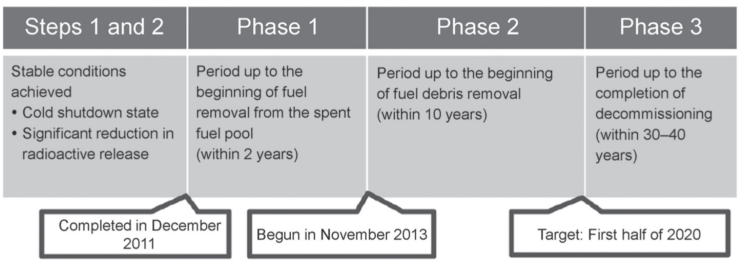


Figure 1 Outline of Mid-and-Long-Term Roadmap

[a] One of the steps deemed necessary to remedy the Fukushima accident by bringing the release of radioactive materials under control and significantly reducing the radiation dose rate (cold shutdown state). This condition was achieved in December 2011.

[b] Large circulation loops: loops currently used for circulation. Circulation loops inside buildings: loops used to bypass the equipment that is currently being used for the treatment of contaminated water to inject stagnant water inside the buildings into the reactors. Small circulation loops: loops that circulate water inside the PCVs after the water leakage has been terminated inside them. Details of changes to the loops are determined according to how the water leakage is terminated and how the infiltration of ground water is prevented.

(e) Examination and sampling inside reactors

(f) Removal, transport, and storage of fuel debris

Adequate measures must be taken to prevent criticality by assessing the impact that each step has on the criticality safety management for fuel debris.

In Step (b), an alternative method of removing fuel debris without filling with water is considered if the water leakage cannot be terminated. In this case, the possibility of criticality can be considered almost negligible in the absence of water as a moderator. If a shielding material is used, its neutron reflection and moderation effects need to be taken into consideration.

III. Challenges Involving Critical Safety

1. Approach to Criticality Assessment

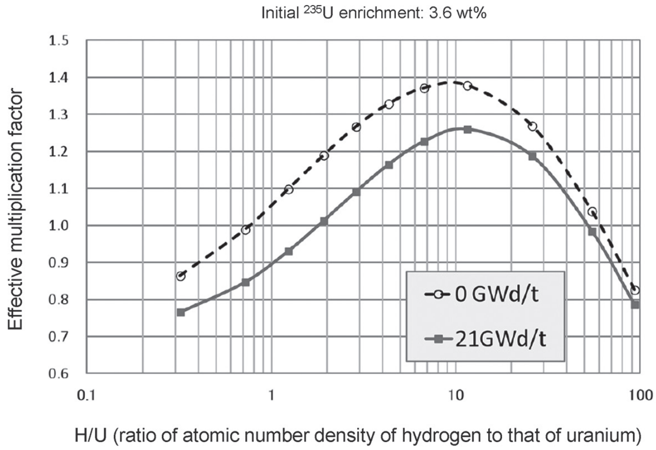
One of the goals set under the Mid-and-Long-Term Roadmap is quick completion of the decommissioning process while always ensuring safety. The quick completion of this process is intended to reduce the risk posed by a failure of the due containment function at the Fukushima Daiichi Plant quickly even though stable conditions have been achieved. Obviously, the top priority in criticality safety management during the removal of fuel debris is to prevent any criticality events having a significant impact on the public, workers, and the environment. In addition, the removal must be performed and completed as early as possible.

The key to achieving this is to conduct the work efficiently while ensuring safety based on realistic assumptions that reflect the actual conditions at the site. Criticality should also be assessed by using the best estimate based on actual conditions rather than excessively conservative conditions that go beyond the realistic settings used in ordinary safety assessments. To this end, the possible range of change (error) must be assessed for the estimated results. Realistic assessments require information related to the fuel debris, such as its composition, density, and distribution. If any missing information must be replaced with estimates, conservative settings must be applied while taking into account estimation errors. For this reason, examinations must be conducted inside the PCVs and reactor pressure vessels as soon as possible.

2. Assessment of the Possibility of Criticality

(1) Assessment of Criticality

The composition of fuel can be assessed based on operational management data, such as the operational history of each reactor. If we assume that the composition of the fuel debris is homogenous, its composition can also be assessed. However, analysis of the fuel debris from TMI-2 indicates that the composition is influenced considerably by the way the fuel melts. For this reason, a homogenous composition of the fuel debris is only hypothetical. Nonetheless, criticality was assessed based on a homogenous fuel of the Fukushima Daiichi Plant to determine what condition would cause the fuel to reach criticality. **Figure 2** presents the H/U dependency of the effective multiplication factor for a spherical core with a homogenous distribution of UO_2 powder in water (H_2O) and a burnup of 21 GWd/t as well as the dependency of fresh fuel (0 GWd/t). This example assumes an initial amount of uranium of roughly 100 tons in an assembly of 548 fuel assemblies that have been loaded in both Units 2 and 3, and it can be considered as an almost infinite system. The burnup of 21 GWd/t simulates the average burnup of 21.8 GWd/t in Unit 3. The H/U on the figure's horizontal axis is the ratio of the



H/U	0.7	2.0	10	50	60
U cconcentration (gU/liter)	7700	5600	2000	500	420
Water content (Vol%)	20	42	79	95	96

Figure 2 H/U dependency of the effective multiplication factor for UO_2 fuel [2)]

atomic number density of hydrogen to that of uranium, which represents the degree of neutron moderation. The table below the figure presents the uranium concentration and water content corresponding to typical H/U ratios. In the assessment of the effective multiplication factor for burned fuel, FP nuclides were applied in the manner accepted for the assessment of burnup credit in accordance with the Criticality Safety Handbook [8)]. Structural materials and control rods (B_4C) were assumed to be absent.

Figure 2 indicates that an H/U ratio of around 10 achieves the optimal moderation for both the burned fuel and the fresh fuel, so it gives the largest effective multiplication factor. Criticality was reached for the burned fuel with an H/U ratio in the range of 2.0 to 50 and for the fresh fuel with an H/U ratio in the range of 0.7 to 60. These ranges correspond to a uranium concentration of between 400 and 7,700 gU/L, which is quite a dense uranium solution. Such a condition may be produced in a transient manner, such as in a case where fuel debris in a powder form is agitated by cooling water. In terms of the volume ratio (water content), criticality can be reached within a wide range of between 20 and 96%. The infiltration of water into pores of fuel debris could lead to criticality being reached. Burned fuel in the optimal moderation condition reaches criticality with about 300 kg of uranium [c]. However, this assessment does not take into account structural materials, absorbers, and impurities or other substances in water. It assumes that the fuel has the spherical shape that most easily reaches criticality. Although this is hypothetical, it should be noted that a critical mass of just 0.3% of the loaded fuel in the reactor (ca. 100 tons) could trigger criticality.

(2) Possibility of criticality during cooldown

As was explained earlier, most of the fuel in Unit 1 is assumed to have dropped to the pedestal of the PCV with almost none remaining in the core. In contrast, some of the fuel is assumed to have remained in the core regions of Units 2 and 3, with the rest having dropped to the bottom of the pressure vessels or the pedestals of the PCVs. Cooling water is injected

[c] Figure 2 indicates that the effective multiplication factor at the optimal moderation is about 1.28. This value was treated as the infinite multiplication factor for determining the radius of a sphere that causes criticality. Assuming that the migration area M^2 is 33 cm^2, the geometric buckling of a spherical reactor resulted in a radius of about 34 cm and 330 kg of uranium.

using the feedwater systems and core spray systems. Each feedwater system injects water into the bottom of the reactor pressure vessel through the outside of the shroud. The core spray system injects water directly into the core region. However, a significant amount of cooling water is not expected to be present in the core region because the pressure vessel in each reactor has been damaged. The water level inside the PCV varies for each reactor (see section II. 1), which reflects the extent of damage sustained by each PCV.

Units 1 to 3 are equipped with PCV gas management systems[9)] that are designed to remove airborne radioactive materials to minimize their external release and to monitor the hydrogen gas concentration. These gas management systems are employed simultaneously to monitor the criticality of fuel debris. By measuring Xe-135 as a fission product[d], these systems classify any Xe-135 concentration that exceeds 1 Bq/cm^3 (about 100 times the Xe-135 concentration produced by the spontaneous fission of Cm-244, etc.) as criticality. This threshold amounts to an output of around 10 W. Criticality is also determined based on changes in the temperature of a reactor pressure vessel and the air dose rate at each monitoring post. No criticality has been identified to date, so it can be concluded that no significant criticality has taken place. In response to any sign of criticality, a boric-acid solution is to be injected through the injection systems.

The Fukushima Daiichi Plant has experienced many earthquakes (aftershocks) and changes in the volume of cooling water since the cold shutdown state was announced. It can be assumed that the future risk of criticality is extremely low given that these events are not believed to have caused any significant changes in the criticality. However, adequate monitoring is required if there is a possibility of events occurring that may change the distribution and shape of the fuel debris.

(3) Possibility of criticality during removal

Water is supplied after the PCVs have been repaired and the water leakage has been terminated in preparation for the removal of fuel debris. This operation floods areas that have not previously been exposed to water, could trigger criticality. However, given that criticality is approached based on the speed of the water injection, signs of criticality can reasonably be detected by adequate monitoring. Assuming a moderate reactivity increase, even if the operation results in criticality (or excess criticality), measures to stop any further reactivity insertion can be taken by detecting such a development before the reaction has advanced too much. If a large amount of fuel debris may move while the water is being supplied, similar measures to those taken for the removal of fuel debris, described below, must be introduced.

The possibility of criticality is at its greatest during the sampling and full-scale removal of fuel debris after the water has been supplied because the shapes and positions of the fuel debris are changed directly. A relatively large rise in reactivity can be expected to occur in a short period of time if a large amount of fuel debris collapses or falls down during the removal process and piles up in the bottom of the pressure vessels and/or on the pedestals of the PCVs. Therefore, before the removal process begins, necessary measures must be implemented by adequately checking the condition of the fuel debris. Depending on the circumstances, it may be necessary to mix a neutron absorber[e] into the system.

[d] Xe-135 is mainly produced by the decay of I-135 with a half-life of 6.6 hours, which causes a time delay in any changes in the concentration. For this reason, an alternative system is being developed to enhance the response speed by switching the detected nuclide from Xe-135 to Kr-87 and Kr-88.

[e] It is evaluated that the full injection of a boric-acid solution into the PCV would require about 200 tons of boric acid. The other problems that also exist include equipment corrosion and waste liquid treatment. For these reasons, the use of neutron absorbers in pellet or gel form has been proposed to facilitate criticality safety management during the fuel debris removal (2013 Spring Meeting of the Atomic Energy Society of Japan, H34).

3. Criticality Events

Any criticality of the fuel debris may potentially affect workers and the public through exposure to radiation as well as the public and the environment through the release of gaseous radioactive materials.

Fuel debris is present in the reactor pressure vessels or the PCVs. The removal of fuel debris in such a high-dose radiation field is mainly conducted remotely. The impact of radiation exposure on workers and the public is most likely minute because any criticality involving radiation would occur inside adequate shielding. Additional shielding must be installed along with the implementation of other necessary measures in case the fuel debris may reach criticality outside of a PCV.

The impact that the release of gaseous radioactive materials may have on the surrounding environment depends on the magnitude of criticality (power and duration). If any criticality remains low, the impact on the surrounding environment is also minor. In principle, it is desirable to avoid any criticality. However, the overall risks do not change if any criticality has only a negligible impact on the surrounding environment. It must be noted that any overly complex and lengthy procedure for preventing criticality can actually result in even higher overall risks.

TEPCO has assessed the dose rate from exposure to the noble gases and iodine produced during criticality. The estimated exposure dose rate is 24 μSv around the site if criticality with the power of 1 kW lasts for 24 hours (24 kWh) [10]. Thus, the power of 100 kW for 10 hours (1,000 kWh) would result in a dose rate of 1 mSv. These estimates ignore the normal containment function, so they will be lower if containment function is taken into account. For this reason, the impact that any criticality has on the surrounding environment can be kept low if it is detected early enough and brought under control quickly. To this end, a technology must be established for the early detection of any signs of imminent or actual criticality and adequate shut measures must be introduced to enable the situation to be brought under control quickly.

If the reactivity surges due to the relocation of a large amount of fuel debris, a significant number of nuclear fissions may take place before criticality is detected and a shut measure is initiated, thereby leading to the release of a large amount of gaseous radioactive materials. The magnitude of criticality depends on the added reactivity. Mechanically unrestrained fuel debris can be returned to subcriticality in a relatively short time as its shape changes due to the mechanical energy release associated with a rapid power increase. Heat can easily transfer from the fuel debris into the water through the large surface area. Therefore, a major steam explosion that may damage the reactor pressure vessels or the PCVs is unlikely. Nonetheless, the condition of the fuel debris must be examined before any work that involves a change in the shape of the fuel debris is conducted in order to take necessary measures against rapid reactivity insertion.

IV. Future Tasks

The following tasks must be considered in line with the discussions conducted to date with respect to criticality safety management during fuel debris removal.

− Ascertainment of the current condition

Clarify the composition, density, and location of fuel debris. The required tasks include clarification of the melting process using analysis codes and so on, examination of the inside of the reactors, and sampling and analysis of samples.

− Validation of the critical assessment

Confirm the validity of the accuracy (errors) of the critical assessment based on the above-mentioned understanding of the current condition.

− Detection of criticality and implementation of shut measures

Develop an early detection system for identifying signs or actual evidence of criticality and a system for quickly returning any detected criticality to subcriticality. Confirm the effectiveness of these systems in terms of their ability to detect and stop criticality.

− Evaluation of overall risks

Extract risk factors for the removal of fuel debris, including those involved in criticality safety management. Evaluate the overall risks in various scenarios and consider measures for reducing these risks to ensure the safety of the public and workers and protect the environment. The implementation of these measures requires the disclosure of information to gain the understanding of stakeholders.

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Commentary

Remote-Controlled Technology and Robot Technology for Accident Response and Decommissioning of Fukushima Nuclear Power Plant

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In the aftermath of the accident that occurred at TEPCO's Fukushima Daiichi Nuclear Power Plant, robots and remote-controlled equipment had to be deployed to perform various tasks in a high-radiation environment. This commentary describes the robots and remote-controlled equipment deployed to date and explains ongoing technological developments for the decommissioning. It further discusses what measures should be taken in anticipation of the decommissioning of the Fukushima Nuclear Power Plant and any possible future disasters.

I. Introduction

In the aftermath of the accident that occurred at TEPCO's Fukushima Daiichi Nuclear Power Plant, robots and remote-controlled equipment had to be deployed to perform various tasks in a high-radiation environment [1)]. Despite the difficulties involved in deploying such equipment immediately after the accident, more than 30 different types of robotic technologies have been employed so far, and they have made a significant contribution to performing the tasks required to respond to the accident and prepare for the decommissioning work. This commentary describes the robots and remote-controlled equipment deployed to date and explains ongoing technological developments for the decommissioning. It further discusses what types of technologies need to be developed in anticipation of the decommissioning of the Fukushima Nuclear Power Plant and what measures should be taken to prepare for any possible future accidents.

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II. Need for the Effective Application of Robotics in Response to the Accident at the Fukushima Daiichi Nuclear Power Plant

In the initial response to the accident, robots and remote-controlled equipment were assigned to perform tasks such as assessing the conditions there, cooling and stabilizing the reactors and spent fuel pools, containing any contaminants, and removing debris to prepare a better working environment. Since the attainment of a cold shutdown in January 2012, robots and remote-controlled equipment have been assigned to remove fuel from the spent fuel pools and fuel debris to prepare for the decommissioning work. Nonetheless, their top priority remains to minimize the radiation exposure of workers who carry out various on-site tasks.

Immediately after the accident, the Japanese government and TEPCO set up six special project teams for handling the accident response and recovery efforts at the Fukushima Daiichi Nuclear Power Plant. One of these teams was the Remote Control Project Team, which was established to discuss how robots and remote-controlled equipment could be deployed on the site.

The government and TEPCO drew up a tentative roadmap for remedying the accident at the Fukushima Daiichi Plant, and emergency response activities were carried out accordingly. Immediately after the accident, robots and remote-controlled equipment had to be mobilized to perform a variety of tasks because the extremely high levels of radiation emitted by the contaminants released around the reactor buildings made it extremely difficult for workers to approach the site. During that initial phase, the emergency response was often quite chaotic. TEPCO, the user of this remote-controlled equipment, could not keep track of the characteristics and sources of the available robotic technologies. Meanwhile, the researchers and manufacturers involved in developing robots could not fully understand what types of solutions were required and where they would be applied. To address this problem, robotics researchers and engineers began exchanging information regarding the ongoing accident response and established the Robotics Taskforce for Anti-Disaster (ROBOTAD) [2)]. In addition to collecting information on available robotic technologies, they conducted technical discussions both online and in person regarding the deployment of robots at disaster or accident sites. The topics that were discussed included the resistance of robot components to radiation and the possibility of employing wireless communication for the remote control of robots inside the reactor buildings. They also supported the Remote Control Project Team, which had been established by the Japanese government and TEPCO, through the provision of various kinds of information.

There was an extremely wide-ranging need for robotic solutions to be employed in the emergency response and decommissioning. Specific examples of these solutions included the following: cooling by water injection; surveys conducted both inside and outside buildings (image capturing as well as measuring of the radiation dose, temperature, humidity, and oxygen concentration); debris removal; transport and installation of equipment and materials; sampling of dust, contaminated water, and fuel debris; shielding; and decontamination. These assigned tasks also had to be carried out in a wide range of places with diverse environmental conditions. Many different types of robotic technologies have been employed to address this variety of requirements.

III. Effective Employment of Robotic Technologies in the Accident Response

1. Cooling

In the immediate aftermath of the accident at TEPCO's Fukushima Daiichi Nuclear Power Plant, the most pressing task was the cooling of reactors and spent fuel pools. At Unit 4, mobile concrete pumps manufactured by Sany Heavy Industry (China) and Putzmeister were deployed on March 22, 2011, to enable water to be safely injected. Other types of pumps were deployed at Units 1, 3, and 4 after a modification had been applied to facilitate remote control. These pumps were called by various pet names, such as elephant, giraffe, mammoth, and zebra. The boom (arm) of each mobile concrete pump was remotely controlled via wireless LAN by using a light and camera mounted on the tip of the boom to ensure that the water injection could be performed stably while the video captured by the camera was monitored in an anti-seismic building.

2. Debris Removal

On April 6, 2011, debris removal was initiated using unmanned construction machines. Immediately after the accident, the premises of the Fukushima Daiichi Nuclear Power Plant were full of debris from the tsunami and the hydrogen explosion that occurred at the reactor buildings. The debris produced by the hydrogen explosion had particularly high levels of radiation, which proved a considerable obstruction to recovery efforts at the site. A joint venture formed by Taisei Corporation, Kajima Corporation, and Shimizu Corporation deployed unmanned construction machines to remove the debris, thereby reducing the exposure dose for workers carrying out tasks in this high-radiation environment. These machines included backhoes, tracked dump trucks, operator vehicles, and camera vehicles.

Equipped with a grab, each unmanned backhoe was remotely controlled to load debris into containers. The unmanned tracked dump trucks were then remotely controlled to transport the containers to the storage site. The removal of debris using these unmanned construction machines continued for about seven months until November. As a result, about 20,000 m^3 of debris (outdoor debris only) was removed from an area of about 56,000 m^2.

After that, debris removal was initiated on May 10, 2011, using remote-controlled equipment both inside and outside of carry-in entrance for large equipment located at the reactor building for Unit 3. The equipment that was deployed included the Talon and Bob Cat, manufactured by QinetiQ (United States), and the Brokk-90 and Brokk-330, manufactured by Brokk (Sweden). This equipment was also employed to remove large amounts of highly radioactive debris from inside the reactor buildings that had experienced a hydrogen explosion. Debris removal was performed with the two Talon units directly provided by QinetiQ. Another Talon unit provided by the Idaho National Laboratory was deployed for other purpose. On July 25, 2013, the ASTACO-SoRa, manufactured by Hitachi Engineering & Services, was deployed as a type of remote-controlled heavy machinery to remove debris and other obstacles from the ground floor of the reactor building for Unit 3.

Debris removal was performed remotely on the top floor of each reactor building that had experienced a hydrogen explosion. The debris in the reactor building for Unit 4 was removed by manned construction machines, since the radiation level was low. In contrast, debris was removed from the reactor building for Unit 3 remotely because of the high levels of radiation there. Unmanned cranes, backhoes (nibblers), and other heavy machinery were deployed on the ground and on the platform that had been built around the reactor building to reduce the exposure dose for workers.

On June 24, 2013, Kajima Corporation announced that complete automation had been achieved for the transportation of highly radioactive debris from Unit 3. This automated transportation is being performed by unmanned tracked dump trucks for a distance of about 1 km from the debris removal site in the reactor building to the on-site storage facility. Round trips from the storage facility to the storage site, which include a slope with a gradient of 7% and a K-turn and cover a distance of around 800 m, are carried out by unmanned folk lifts.

3. Surveys

On April 17, 2011, a survey was initiated inside the reactor buildings by using two PackBot units, manufactured by iRobot (United States). Initially, these robots were used to measure the radiation dose, ambient temperature, ambient humidity, and oxygen concentration. Since then, the PackBots have been deployed many times to perform various other tasks, such as checking the integrity of the core spray systems and surveying the ground floor of the reactor buildings.

In June 2011, the Quince was deployed extensively in missions that required moving up and down stairs inside buildings. Capable of crossing over debris and other obstacles, this robot was developed by organizations including the Chiba Institute of Technology, Tohoku University, the International Rescue System (IRS), and the New Energy and Industrial Technology Development Organization (NEDO). The Quince failed to accomplish its mission to sample contaminated water in the basement and install a water level indicator on June 24, 2011. However, it made a remarkable contribution to a survey conducted of the third floor of Unit 2 on July 8, 2011. It was also deployed effectively along with the PackBot to check a core spray system on July 22, 2011. On October 20, 2011, it successfully completed a survey on the fifth floor of Unit 2. However, communication problems caused it to become inoperative on the third floor while it was returning from its mission. Later, the Quince 2 and the Quince 3, which are the same type of model, were deployed. These robots are effective in conducting indoor surveys, such as the one conducted for the main steam isolation valve (MSIV) room on the ground floor of the reactor building for Unit 2.

Other robots and equipment such as the following were also deployed to conduct various surveys in reactor buildings that cannot be easily accessed by workers: the JAEA-3, a survey robot developed by the Japan Atomic Energy Agency (JAEA); the Survey Runner, developed by Topy Industries; the FRIGO-MA, developed by Mitsubishi Electric TOKKI Systems; a robot developed by Honda and AIST for surveying elevated spots; and a quadrupedal robot and a small vehicle developed by Toshiba.

In addition to the deployment of these robots and remote-controlled equipment, robotic solutions such as the following have also been employed to conduct various surveys: the T-Hawk, a small-scale unmanned helicopter manufactured by Honeywell (United States), conducted an aerial survey of the reactor buildings; an industrial fiberscope was deployed in a survey conducted inside the primary containment vessel for Unit 2; the ROV, an underwater robot manufactured by Hitachi, surveyed the inside of the spent fuel pool for Unit 4 and drew a debris distribution map; a balloon manufactured by Hitachi was employed in a survey of the operation floor for Unit 1; the RC-1, a robot-operated vehicle manufactured by the JAEA, was deployed in a survey conducted together with the Talon, a robot manufactured by QinetiQ (United States); and measurements of the dose distribution were taken using a gamma camera.

On November 13, 2013, an underwater survey robot developed in a project (described later) conducted by the Agency for Natural Resources and Energy (ANRE) identified contaminated water leaking from the primary containment vessel into the torus room. This robot was developed by Hitachi-GE Nuclear Energy based on discussions held by the Remote Control Task Force and more detailed discussions held by one of its working groups headed by Professor Tamaki Ura, who works at the Kyushu Institute of Technology. Many other robots had been deployed earlier to locate contaminated water leaks, but this first discovery of a leak by a robot is worth mentioning.

4. Decontamination

From the end of June to the beginning of July in 2011, the Warrior and PackBot, manufactured by iRobot (United States), were deployed to clean the reactor building for Unit 3. A cleaning system was mounted on the Warrior in an attempt to clean and decontaminate the floor surface and reduce the ambient dose rate, but this had little effect. However, the Warrior is still used to move obstacles in the reactor building for Unit 3.

Since November 28, 2013, the decontamination of the ground floor in the reactor building for Unit 2 has been conducted through the remote operation of a decontamination system developed by ATOX. Various other solutions have gradually been introduced as well, including a scabbler manufactured by Pentek as well as a high-pressure washing unit, dry-ice blasting unit, and blast and vacuum recovery unit developed with grants awarded by ANRE (described later).

IV. Development of Robotic Technologies for Decommissioning

The Japan Atomic Energy Commission's Special Committee on Mid-and-Long-Term Measures for TEPCO's Fukushima Daiichi Nuclear Power Plant discussed how to overcome these extremely difficult challenges to achieve their mission [3]. They presented Mid-and-Long-Term Roadmap towards the Decommissioning [4] together with the following two tasks related to research and development in preparation for the decommissioning work.

− The Japanese government is to pursue the necessary research and development responsibly.

− The accident is to be brought under control over the mid- to long-term with assembling domestic and international wisdom.

Accordingly, the Japanese government and TEPCO established the Research and Development Task Force for the Conference on Mid-and-Long-Term Measures as well as a steering committee for managing the progress made in accordance with the Mid-and-Long-Term Roadmap. Both of these bodies conduct research and development for the Mid-and-Long-Term measures. In February 2013, the abovementioned conference was discontinued to reinforce the support mechanism for the decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Plant. Instead, the Council for the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Plant was established. A detailed verification of the progress made in preparation for the decommissioning work is being conducted by a secretariat conference of the Advisory Committee for Decommissioning (meetings by the teams presently in charge of decommissioning and implementing measures for contaminated water).

Meanwhile, in August 2013, the International Research Institute for Nuclear Decommissioning (IRID) was established as an association for conducting research and development related to decommissioning technologies by bringing together knowledge from Japan and overseas. This institute will take the lead in such research and development going forward.

The following sections present examples of the research and development related to robots and remote-controlled equipment that has been conducted to date in preparation for the decommissioning work.

1. Research and Development Related to Remote-Controlled Equipment That Has Been Subsidized or Commissioned by the ANRE

In FY2012, three nuclear power plant manufacturers (Hitachi-GE Nuclear Energy, Toshiba, and Mitsubishi Heavy Industries) conducted research and development for projects that were subsidized or commissioned by ANRE under Japan's Ministry of Economy, Trade and Industry (METI). Grants of 500 million yen were allocated for the development of technologies to be used in responding to accidents at commercial nuclear power reactors. Another 1.5 billion yen was commissioned for infrastructure improvements. These research and development activities included the decontamination of inside reactor buildings, the conducting of surveys on leaks from reactor buildings and primary containment vessels, the conducting of surveys inside primary containment vessels, the plugging of leaks at reactor buildings, the conducting of repairs to the bottom of primary containment vessels, and the conducting of long-term assessments to validate the integrity of pressure vessels and primary containment vessels in relation to corrosion.

These three plant manufacturers issued calls for proposals to study applicable technologies required for the development of these technologies by bringing together insights from Japan and overseas, which were then compiled in a technology catalog [5)]. According to this catalog, a call for proposals was issued for each type of technology to be developed to incorporate useful technologies from Japan and overseas.

In FY2013, ANRE allocated a budget for subsidizing development projects and commissioning the decommissioning of commercial power reactors and improving the safety infrastructure. Work on the development of the following technologies is underway: technologies for identifying and repairing leaks from primary containment vessels, technologies for examining the inside of primary containment vessels, technologies for remote-controlled decontamination, technologies for examining the inside of pressure vessels, and technologies for containing, transporting and storing fuel debris.

2. Remote Control Task Force

The abovementioned Research and Development Task Force for the Conference on Mid-and-Long-Term Measures, which was established by the Japanese government and TEPCO, conducted individual projects for the respective R&D missions. Taking into account the many challenges that are expected in relation to the development of robots and remote-controlled equipment, the Remote Control Task Force was established as a cross-sectional unit that would cover all projects. This unit is assigned to examine how robot technologies should be applied to address the various needs and achieve the respective missions, propose solutions, propose backup plans in case an approach fails, establish specific R&D projects, and provide advice on the implementation of these projects.

In addition to the development of equipment as mentioned earlier, working groups were established to accomplish the respective missions and discuss the remote control systems to be deployed. These missions include the conducting of surveys of the rooftops of reactor buildings, the conducting of surveys of leaks from suppression chambers, and the measurement of water levels in suppression chambers. More specifically, these working groups are investigating the use of various measurement methods and survey systems that employ small airships, small unmanned helicopters, suspension mechanisms, and underwater survey robots. In FY2012, for instance, a working group led by Professor Matsuhira of the Shibaura Institute of Technology developed a remote-controlled device for measuring the water level inside a suspension chamber through the development of basic technologies for the remote-controlled measurement of the water level in a cylindrical container under a project for developing a technological platform for responding to accidents at commercial reactors that was conducted by ANRE under METI. In addition, a remote-controlled underwater survey robot was developed during the technological development of underwater survey robots for the advancement of a technological platform for remote-controlled operations. These inventions have already been deployed, and they have produced remarkable outcomes.

Another working group led by Professor Yoneda of the Chiba Institute of Technology was established under the Remote Control Task Force when a quadrupedal robot encountered some trouble during a survey around the bottom part of the venting pipes in a suppression chamber. The working group examined the problem and proposed a modification. Subsequently, appropriate measures were implemented based on this examination and the survey around the bottom part of the venting pipes was successfully completed.

The development of robots and remote-controlled equipment needs to be continued by the Advisory Committee for Decommissioning after the task has been carried over from the Research and Development Task Force for the Conference on Mid-and-Long-Term Measures, which was established by the Japanese government and TEPCO. The role of the Remote Control Task Force is expected to be continued by the IRID, which was, as mentioned earlier, established as an association for conducting research and development related to decommissioning technologies.

3. Project for Unmanned Disaster Response Systems

NEDO implemented a third supplemental budget of 1 billion yen for an unmanned disaster response system project [6] in FY2011 to develop common platforms for disaster responses. This project was implemented due to the perceived need for practical robots (unmanned systems) that can respond to disasters in Japan. Working and traveling mechanisms are being developed to carry out unmanned monitoring operations by approaching environments that contain hazardous contaminants in spaces that are too small or difficult for workers to access.

The items being developed are as follows.

(1) Development of working and traveling mechanisms

[1] Development of small remote-controlled travel units with an excellent obstacle crossing capacity
[2] Development of communication technologies
[3] Development of remote-controlled human interfaces
[4] Development of remote-controlled wheeled platforms for loading and handling heavy objects in small spaces
[5] Development of remote-controlled handling platforms for loading heavy objects

(2) Development of underlying technologies for measurements and work

[6] Development and improvement of devices for monitoring and handling operations in the air and underwater

(a) Development of gamma cameras

(b) Development of contamination mapping technologies

(c) Development of training simulators for robot operations conducted during disaster responses

(d) Development of amphibian traveling units

(3) Development of assistant robots for disaster responses

[7] Development of assistant robots

This project has not been undertaken as part of efforts to respond to nuclear accidents, but the technologies being developed under this project are deemed applicable to the Mid-and-Long-Term Measures being taken in response to the Fukushima Nuclear Accident. There are high expectations that these technologies will be deployed extensively in preparation for the decommissioning work.

V. Future Tasks

1. Preparations for Decommissioning

In November 2013, the removal of fuel from spent fuel pools marked the beginning of Phase 2 under the Mid-and-Long-Term Roadmap. However, the decommissioning work is expected to take about 30 to 40 years, and it will require the completion of a series of tasks that cannot be performed easily by workers, such as the conducting of decontamination work, the identification and repair of contaminated water leaks, and the conducting of surveys and removal of fuel debris. Consequently, robots and remote-controlled equipment must be continuously developed in preparation for the decommissioning work. According to the current roadmap, the removal of fuel debris is scheduled to take place after the primary containment vessels have been repaired and shielded with water. In practice, however, the performance of integrity checks and the conducting of repairs so that the vessels can be filled with water is expected to prove extremely difficult. As a backup, it may be necessary to develop technologies for removing fuel debris from the air. In that event, the necessary equipment will be need to have a high level of resistance against radiation, so robust base technologies must be developed.

All of the robots and remote-controlled equipment required for the decommissioning work will need to be developed from scratch. Even after the research and development has been completed, the robots and remote-controlled equipment will need to be sufficiently sophisticated to be able to perform their roles reliably. They will also need to be deployed only after due verification of their functions, demonstration tests, and operator training. Having established the Fukushima Nuclear Plant Decommissioning Safety Research Establishment, the JAEA is carrying out its plan to construct and operate a facility to demonstrate remote-controlled equipment and devices (known as a “mockup facility”). This facility will play a crucial role in function verification, demonstration tests, and operator training.

2. Preparations for a Nuclear Emergency

Germany and France have respectively established the KHG (1977) and Groupe INTRA (1988) as organizations for responding to a nuclear emergency. Both of these organizations maintain robots and other equipment to facilitate a practical response to a nuclear emergency by regularly trained operators. They are able to deploy the necessary equipment and personnel to any nuclear accident site within 24 hours. In Japan, the Fukushima Nuclear Accident has renewed the nation's awareness on the extreme importance of making preparations for any possible nuclear emergencies.

The Federation of Electric Power Companies of Japan (FEPC) intends to set up Nuclear Emergency Support Team in FY2015 in accordance with its goal of establishing a support mechanism for responding effectively to nuclear accidents through a diverse range and high level of measures. Furthermore, the Japan Atomic Power Company established the Nuclear Emergency Support Center and began to procure disaster response robots and conduct training program for the operators. The center plans to build up its capacity by procuring, deploying, and operating various types of robots so that it can respond to a wide range of disasters that require different kinds of operations under complex environments.

3. Robots for Disaster Preparedness

Japan is prone to a wide range of natural disasters, including earthquakes, tsunamis, typhoons, and volcanic eruptions. In addition, the country is experiencing a surging number of accidents associated with a deterioration of its social infrastructure (e.g., tunnels, bridges, expressways, and dams) and its industrial infrastructure (e.g., chemical plants and industrial complexes).

Since FY2011, the Council of Competitiveness-Nippon has been conducting projects related to disaster response robots. The council has been developing robotic technologies for responding to disasters and exploring measures for building their operation systems. They have also compiled recommendations related to applying these technologies to hone the industrial competitiveness of Japan [7-9]. Due to space limitations, detailed recommendations will be presented in a different report [10]. Aside from the necessary research, development, and demonstration tests, the key point in maintaining robots for emergency preparedness is to ensure their regular use.

The Fukushima Nuclear Accident has presented us with the long-lasting task of decommissioning through the development and application of robotic technologies. These technologies are expected to drive the practical application of disaster response robots in society.

VI. Conclusions

This commentary describes the various types of robots and remote-controlled equipment that have been deployed so far to respond to the accident at TEPCO's Fukushima Daiichi Nuclear Power Plant. It explains the technologies that need to be developed and applied in preparation for the decommissioning as well as in preparation for any future nuclear accidents. This commentary owes its insights to information related to the on-site deployment of robots and remote-controlled equipment that has been provided by Mr. Shin Yoshino and Mr. Tsutomu Tanaka from TEPCO and Mr. Shinji Kawatsuma from the JAEA.

The experience of Fukushima teaches us that we need to be prepared to mobilize robots and remote-controlled equipment to perform tasks that cannot be performed safely or easily by workers in response to a nuclear emergency, natural disaster, or any other man-made (industrial) disaster involving social and industrial infrastructure. This preparedness is vital for building national resilience.

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Commentary

Safety on Hydrogen Explosion in Nuclear Power Plants

−Explosion Prevention and Protection Based on the Concept of System Safety−

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To prevent hydrogen explosions at nuclear power plants, adequate knowledge of hydrogen's combustion characteristics and the types of explosions must be acquired. In particular, an understanding of the following two types of explosions is vital: deflagrations and detonations. Reasonable explosion prevention and protection measures must be sought with reference to the relevant European standards. More specifically, the measures required are the identification of hazard sources, the conducting of risk assessments, and the pursuit of risk reduction. These measures are based on the concept of system safety. Risks should be rationally reduced to ensure safety.

I. Introduction

In March 2011, the Tohoku earthquake triggered hydrogen explosions at the Fukushima Daiichi Nuclear Power Plant, causing severe damage to the surrounding area. This experience was a fresh reminder of how explosion prevention and protection measures are vital for nuclear power plants. It also highlighted the need for the nuclear sector to acquire sufficient knowledge of the combustion characteristics of hydrogen and other flammable gases and the types of explosions.

Against this background, this commentary outlines differences between a deflagration and a detonation as two types of explosions. It explains how flame propagation accelerates during the deflagration process from the perspective of intrinsic instability. In addition, rational measures for explosion prevention and protection based on the concept of system safety are described with reference to the relevant European standards.

II. Explosions

1. Types of Explosions

According to Physics and Chemistry Dictionary [1], "An explosion is a rapid increase or

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release of pressure associated with the rupturing of a container or a rapid expansion of gas accompanied by a blast sound or rupture. Explosions of vacuum flasks, boilers, and volcanoes are physical ruptures, while explosions of gases, dust, gunpowder, and the like are chemical explosions." According to this definition, the hydrogen explosions experienced at the Fukushima Daiichi Nuclear Power Plant are regarded as chemical explosions. The dictionary further explains that, "Chemical explosions result from intense combustion, decomposition, or other exothermic reactions." This commentary focuses on chemical explosions to outline the types of explosions.

An explosion can be understood by studying what happens when hydrogen or another flammable gas is premixed with air or another gaseous oxidant. Such a gaseous premixture can explode in one of two ways: deflagrations or detonations. The most distinct difference between these two types of explosions is their propagation velocities in that the former is subsonic while the latter is supersonic.

Table 1 presents the typical characteristics of deflagrations and detonations [2]. This comparison assumes a steady one-dimensional flow, wherein M denotes the Mach number (i.e., the ratio of the velocity to that of sound) while u, p, and ρ respectively denote the velocity, pressure, and density. The subscript 1 represents an upstream (unburned) premixture, while the subscript 2 represents a downstream (burned) combustion gas. Table 1 clearly shows that deflagrations and detonations have completely distinct characteristics. Accordingly, the first step is to identify which type of explosion should be subject to close investigation. In general, detonations are considered the more destructive type of explosion.

Table 2 shows the maximum burning velocity for each gaseous premixture [3] at room temperature through a deflagration under atmospheric pressure. Air is employed as a gaseous oxidizer here. Hydrogen deflagration has the highest maximum burning velocity. The upstream and downstream pressures are almost identical since the Mach number of burning velocity is much smaller than 1. Similar to chemical reactions, mass diffusion and heat conduction play important roles in a deflagration.

Table 1 Characteristics of deflagrations and detonations

	Deflagration	Detonation
M_1	0.0001 ~ 0.03	5 ~ 10
u_2 / u_1	4 ~ 16	0.4 ~ 0.7
p_2 / p_1	≈ 0.99	13 ~ 55
ρ_2 / ρ_1	0.06 ~ 0.25	1.4 ~ 2.5

Table 2 Maximum burning velocity in a deflagration

Flammable gas	Maximum burning velocity u_1 (m/s)	Equivalence ratio
Hydrogen	2.912	1.80
Acetylene	1.540	1.30
Ethylene	0.750	1.15
Methane	0.370	1.06
Ethane	0.401	1.14
Propane	0.430	1.14
Butane	0.379	1.13
Carbon monoxide	0.430	2.57

Combustion of a gaseous premixture requires a flammable gas to be concentrated in a certain range within the flammability limits. Such a flammability range is defined by a lower boundary called the “lower flammability limit” and an upper boundary called the “upper flammability limit.” This concentration range between these limits corresponds to flammability range. **Table 3** compares the flammability limits (lower and upper) for premixtures of air and different flammable gases [3]. Similar to acetylene, hydrogen has a broad flammability range so it needs to be handled with particular care.

Detonations can be further divided into several categories. The most common is CJ detonations, which are named after two scientists, Chapman and Jouguet. **Table 4** presents the stoichiometric characteristics of CJ detonations for different gaseous premixtures [3]. Compared to a deflagration, the propagation velocities of CJ detonations are apparently an order of magnitude higher and the pressure of the combustion gases becomes extremely high.

Any detonation of a gaseous premixture requires the concentration of the flammable gas to fit within a certain range (between detonation limits). This range is known to be narrower than the flammability range for any premixture (see Table 3). Any propagation of a deflagration in a gaseous premixture within the detonation limits is accelerated by an increase in the flame surface area to shift further toward a detonation. This phenomenon is called “deflagration-to-detonation transition” (DDT). Many studies have been conducted to investigate this important phenomenon. The transition is usually caused by increased disturbance of a flame surface. The accelerated propagation generates weak pressure waves on the unburned side of the gas. Overlapping each other, these waves produce a strong pressure wave (shock wave) that leads to autoignition and the subsequent detonation of the unburnt gas ahead of the wave [4]. The transition to a detonation can take place in open spaces as well, but it is known to take place more easily in pipes since they tend to accelerate propagation velocity better.

Table 3 Flammability limits for a premixture of a flammable gas and air

Flammable gas	Lower limit (vol%)	Upper limit (vol%)
Hydrogen	4.0	75.0
Acetylene	2.5	100.0
Ethylene	2.7	36.0
Methane	5.0	15.0
Ethane	3.0	12.5
Propane	2.1	9.5
Butane	1.6	8.4
Carbon monoxide	12.5	74.0

Table 4 Stoichiometric characteristics of CJ detonations for different gaseous premixtures

Gaseous premixture	u_1 (m/s)	p_2 (atm)	T_2 (K)
Hydrogen + air	1967	15.6	2951
Hydrogen + oxygen	2834	18.8	3682
Methane + air	1801	17.2	2783
Methane + oxygen	2392	29.4	3727
Propane + air	1795	18.2	2819
Propane + oxygen	2360	36.3	3830

2. Acceleration of Flame Propagation

Once a gaseous premixture (e.g., hydrogen and air) is ignited, the premixed flame or deflagration propagates spherically at an accelerating pace. This phenomenon draws attention in the field of explosion safety (combustion safety). The flame propagation velocity of a premixture is the most vital parameter for ensuring safety, so it needs to be adequately evaluated. Conventionally, the propagation velocity of a spherical deflagration has been evaluated based on the burning velocity of a premixed planar flame while taking into account the thermal expansion of the gas. Nevertheless, there are many reports of spherical deflagrations that involve the formation of cellular flame structures and increased flame surface areas, thereby accelerating the flame propagation velocity [5)]. This formation of cellular structures is particularly salient with respect to a premixture of hydrogen and air due to the intrinsic instability. Propagation accelerates much further in a spherical deflagration inside a vast facility, because the propagation velocity increases with the scale. In the hydrogen explosions that occurred at the Fukushima Daiichi Nuclear Power Plant, giant balls of flames with cellular structures are thought to have grown larger at an accelerating pace of propagation.

For this reason, the acceleration mechanism for flame propagation must be clarified by observing a spherical deflagration triggered by an ignition at the center of an explosion vessel filled with a premixture of hydrogen and air. **Figure 1** shows high-speed imaging of the flame propagation and flame surface shape that was obtained by using the Schlieren method to understand the essential characteristics of hydrogen explosions and obtain the insights necessary to build an acceleration model for flame propagation. The Schlieren method is employed to optically visualize or photograph slight variations in the refraction index in a transparent medium that distorts light beams [1)].

Figure 2 shows how a spherical deflagration propagates with an equivalence ratio ϕ of 1.0 (stoichiometric mixture) and 0.5 (lean mixture), initially at room temperature under atmospheric pressure. After the ignition occurs at the center, the deflagration propagates spherically. The propagation is slower with the equivalence ratio of 0.5 because the burning velocity is lower. Cellular flame surfaces are observed with the spherically propagating flame from the gaseous mixture. This shape results from the development of sufficiently small disturbances associated with intrinsic instability. In general, the possible factors behind this intrinsic instability are the hydrodynamic effects generated by the thermal expansion of the gas and the diffusive-thermal effects generated by interactions between the mass diffusion and heat conduction. These effects shape the cellular flames. Markedly uneven cell surfaces are formed with the equivalence ratio of 0.5. In comparison to the results for a ratio of 1.0, the diffusive-thermal effects are more pronounced and they increase the level of instability. It is confirmed

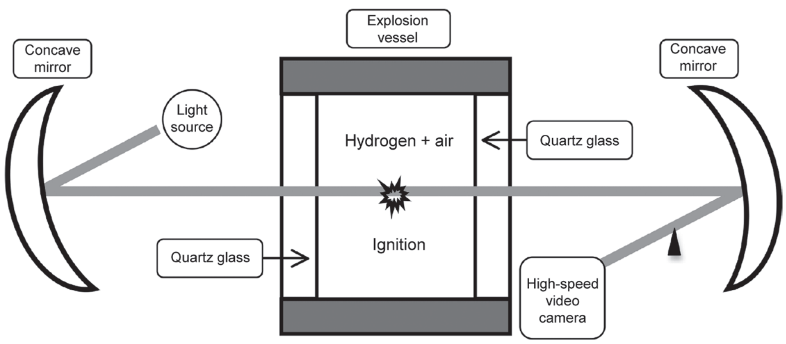

Figure 1 Overview of experimental equipment for investigating hydrogen explosions

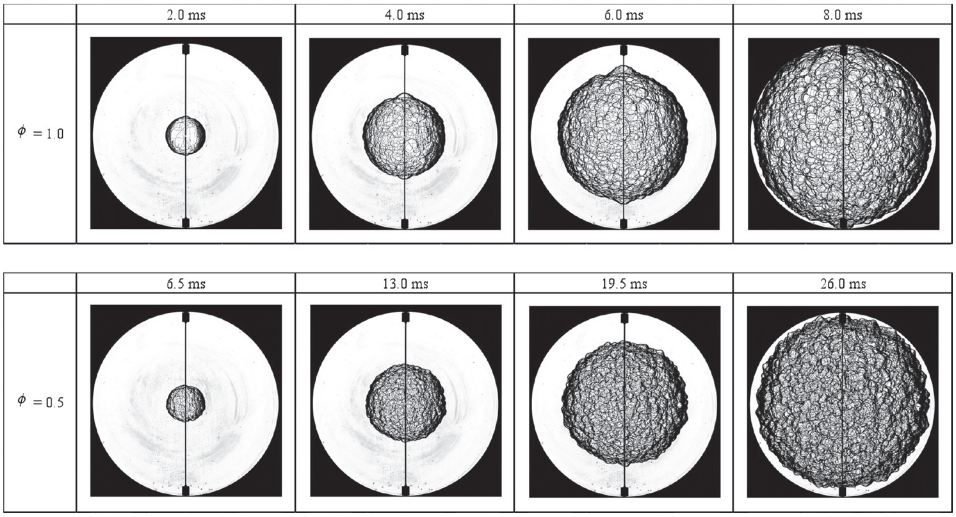

Figure 2 Propagation of a spherical deflagration

that the propagation is visibly accelerated by the increased surface area of the flame.

Experiments on hydrogen explosions will be conducted under various conditions to construct an acceleration model for flame propagation by closely examining how the equivalence ratio, temperature, and pressure influence the acceleration of the propagation velocity. This model is expected to become a useful tool in simulating hydrogen explosions.

III. Safety Standards for Explosion Prevention and Protection

Explosive atmospheres combined with the presence of an ignition source explode and cause harm. In light of this, Europe has established EN 1127-1: 2011, a standard entitled “Explosive Atmospheres—Explosion Prevention and Protection—Part 1: Basic Concepts and Methodology” [6]. This standard was established in line with the essential requirements stipulated by EU Directive 94/9/EC (ATEX) and the Machinery Directive 2006/42/EC.

The European standard EN 1127-1: 2011 seeks to reduce risks by pursuing prevention first, then protection, and finally information sharing. The same order is used in the three-step method adopted in ISO12100: 2010, an international safety standard entitled “Safety of Machinery—General Principles for Design—Risk Assessment and Risk Reduction” [7]. Japan tends to rely on protective measures using explosion-protected electrical equipment (e.g., IEC 60079-0 [8]) and operational information. More properly, risks should be reduced primarily through prevention measures. Other measures should be taken only if the risks cannot be reduced. Ensuring safety by relying on protection and information deviates from the approach adopted in international safety standards. Improvements to address this problem are keenly anticipated.

European standards prescribe the use of zoning classifications based on the quantified probabilities of explosions in explosive atmospheres as well as categories for the equipment, protective systems and components to be deployed in these zones. **Tables 5** and **6** indicate how they correspond to one another, with the former comparing categories and zones from the view of equipment producers and the latter comparing zones and categories from the view

Table 5 Relation between categories and zones (from the view of equipment producers)

Category	Applicable in zone	Explosive atmosphere
1G	0, 1, 2	Gas, steam, or mist + air
2G	1, 2	Gas, steam, or mist + air
3G	2	Gas, steam, or mist + air
1D	20, 21, 22	Dust + air
2D	21, 22	Dust + air
3D	22	Dust + air

Table 6 Relation between zones and categories (from the view of equipment users)

Zone	Applicable category	Explosive atmosphere
0	1G	Gas, steam, or mist + air
1	1G, 2G	Gas, steam, or mist + air
2	1G, 2G, 3G	Gas, steam, or mist + air
20	1D	Dust + air
21	1D, 2D	Dust + air
22	1D, 2D, 3D	Dust + air

of equipment users. These tables indicate which category of equipment can be applicable in which zone and vice versa.

Adequate explosion prevention may even make the deployment of protective equipment unnecessary. This approach is worth considering not only to ensure safety, but also to reduce costs.

IV. Concept of System Safety

System safety is pursued through hardware/software, humans, laws/norms, and various combinations thereof by adopting a system-based approach that applies safety technologies and management methods in an integrated manner. In this process, hazard factors are identified in advance for each stage of the lifecycle, including the designing, manufacturing, and usage stages. The impact of these factors is assessed to implement adequate measures. The definition of "system safety" that is provided in the MIL standard [9)] is based on essentially the same concept. Risks must be rationally reduced according to this concept to ensure system safety.

Explosion prevention and protection measures at nuclear power plants should be pursued in accordance with the abovementioned safety standards. More specifically, the required tasks are the following: identification of hazard sources (e.g., the combustion characteristics, ignition requirements, and nature of explosions), risk assessments (e.g., determination of the probability of an explosive atmosphere and the amount, determination of the presence of an ignition source, and assessment of an explosion's impact), and risk reduction (through prevention, protection, and information measures). These measures echo the concept behind system safety. Crucially, safety needs to be ensured by rationally reducing risks.

V. Conclusions

This commentary outlined and contrasted two different types of explosions: deflagrations and detonations. It explained how flame propagation accelerates in a deflagration from the perspective of intrinsic instability. Safety standards for explosion prevention and protection were presented to explain how rational measures are implemented according to the concept of system safety. The author hopes that these rational measures will be taken to ensure explosion prevention and protection at nuclear power plants with adequate preparedness for any explosions.

This commentary referred to the results of hydrogen explosion experiments recommissioned by the Japan Atomic Energy Agency in a project commissioned by the Agency for Natural Resources and Energy. I would like to express my sincere gratitude for this opportunity.

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Commentary

The Status of R&D on Material Accountancy of Fuel Debris at Fukushima Daiichi Nuclear Power Station

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The removal of the molten core fuel from the reactor vessel at the Fukushima Daiichi Nuclear Power Station is scheduled to begin in around 2020. A method of accounting for and controlling nuclear material in the removed fuel debris is being explored in a research and development project to facilitate the decommissioning of the reactors at the nuclear power station. This commentary describes the current status of this project, which is being led by the Japan Atomic Energy Agency and the Tokyo Electric Power Company.

I. Introduction − Starting Out as Part of a National Decommissioning Project −

The Japanese government and the Tokyo Electric Power Company (TEPCO) had been exploring the necessary technologies for decommissioning the Fukushima Daiichi Nuclear Power Station. One of the agenda items to have been identified is the development of a technology for measuring the quantity of nuclear materials in the molten core fuel. In light of this, a project was launched in April 2012 to develop a method of accounting for and controlling nuclear material in the fuel debris.

This commentary describes the policy and current status of this project, which the author has been engaged in since August 2012.

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II. Method of Accounting for and Controlling Nuclear Material in the Core Fuel − Statutory Accounting for and Control of Nuclear Material and Declaration of the Inventory of Nuclear Material Pursuant to International Safeguards Agreements with the International Atomic Energy Agency (IAEA) −

Prior to the recent nuclear accident, the quantity of nuclear materials in the core fuel had been calculated based on the irradiation history of the fuel and information from the fuel fabrication facility. The quantities of uranium and plutonium per fuel assembly had been recorded along with their physical and chemical forms and locations in the facility and other information related to the fuel assembly. The facility operator submitted such records to the Japanese government pursuant to the domestic law. The government of Japan in turn declared this information to the IAEA pursuant to the safeguards agreement between the IAEA and Japan. However, conducting material accounting in units of assemblies will be difficult as it is unlikely that the fuel assemblies at the Fukushima Daiichi Nuclear Power Station retained their original shapes after the accident. For this reason, an alternative method of material accounting needs to be developed.

III. Role of Nuclear Material Accounting − Changing the Role with the Times −

Initially, in 1960s and 1970s, nuclear facility operators performed accounting for their nuclear materials with the intention of managing their property and safety. Around the 1990s, however, a gap emerged in Japan between the information needed for property and safety management and that needed for nuclear safeguards. The operators realized that it was less necessary for them to acquire information through material accounting for property and safety management than it was for nuclear safeguards. There were two major causes of the abovementioned gap. Firstly, Japan began demonstrating the peaceful use of plutonium during the same period, which required the implementation of strict nuclear safeguards, thereby resulting in material accounting requiring an extremely high degree of accuracy that went beyond the level required for property and safety management. Secondly, the technological criteria for the IAEA safeguards inspections had been established following considerable discussions, so the information required for the inspections was gradually clarified and increased.

The IAEA safeguards that were established during the 1970s under the comprehensive safeguards agreements form a system in which the state requests the IAEA to certify that the country's nuclear materials are not being diverted from peaceful uses. According to the system's basic principle of minimizing any disruption to peaceful nuclear activities, the system was designed so that safeguards verifications are conducted based on the nuclear facility operator's regular nuclear materials accounting and control.

In light of this historical background, the main purpose of nuclear material accounting is now considered part of safeguards in Japan. In principle, however, safeguards implemented by the IAEA are still supposed to take full advantage of the material accounting conducted by the nuclear facility operator according to their own needs. Moreover, inventory management by the facility operator continues to be based on their material accounting and control.

IV. Relationship with IAEA Safeguards − Relationship between the IAEA Safeguards Inspections and Nuclear Material Accounting −

Under its safeguards system, the IAEA validates the inventory of nuclear materials declared by the governments and directly inspects these materials during on-site inspections of the relevant facilities.

Safeguards inspections employ a technology for detecting the diversion of nuclear materials to ensure that no nuclear materials are diverted to other purposes. As nuclear facilities grow in size, they handle an increasing quantity of nuclear materials. Inspections of facilities that handle nuclear materials in bulk require the use of advanced technologies and various kinds of information to deal with the complex handling processes and limitations in relation to measuring the accuracy of nuclear materials. In other words, the nuclear facility operator is required to provide highly accurate and diverse types of information about nuclear materials to conduct safeguards inspections. Consequently, the costs of safeguards implementation have increased while the operator is required to conduct advanced material accounting.

For this reason, methods have been explored to identify the implementation of reasonable material accounting that can be conducted without causing any disruption to peaceful nuclear activities and obtain highly reliable safeguarding outcomes (annual conclusions regarding any signs of nuclear materials being diverted from peaceful purposes) through the inspections. Along the way, the technical requirements for inspections and material accounting have also gradually changed.

In light of this change, the development of a well-balanced material accounting method befitting the intended inspection method is important for facilitating the operation of nuclear facilities. The same holds true for the development of a method of conducting material accounting of fuel debris.

Under the safeguards system, technically advanced safeguards and inspection methods are applied to plutonium and highly enriched uranium as they are classified as materials that can be directly used in the manufacture of weapons. Material accounting must be explored keeping this in mind.

V. Management of Nuclear Materials in Light of Past Core Fuel Accidents − Findings from Similar Cases −

Nuclear material accounting became difficult after the core fuel accidents that occurred at the Three Mile Island Nuclear Power Station (TMI-2) in the United States, the Chernobyl Nuclear Power Plant (ChNPP) in the former USSR, and the Paks Nuclear Power Plant (Paks) in Hungary. In some respects, however, these all differ from the accident in Fukushima. There was no need to declare the quantity of nuclear materials after the accident at TMI-2 as the IAEA safeguards system was not applicable to the United States. Similarly, the former USSR was not subject to IAEA safeguards when the accident took place at ChNPP.

Safeguards measures were applied after the accident when Ukraine gained its independence from the Soviet Union. This means that the nuclear material inventory in the reactor core had not been declared to the IAEA before the accident. Nevertheless, the inventory of nuclear material after the accident had to be managed and controlled for the application of safeguards. At the Paks nuclear plant, a fuel assembly fell apart when the cladding that contained the fuel pellets broke. Fortunately, all of the fuel pellets could be collected as the fuel pellets did not melt. Studies on nuclear material management at these three plants have yielded the following findings.

－ Accounting in relation to removed nuclear materials must be performed in units of containers (TMI-2 and Paks).

－ Containment monitoring can be conducted as a safeguarding method to confirm that materials from affected reactors are not being diverted (ChNPP and Paks).

－ Some kind of safeguarding method must be applied to containers for removed nuclear materials (ChNPP and Paks).

－ There is no precedent for the direct and precise measurement of the quantity of nuclear materials from outside a container. However, the quantity of nuclear materials was once estimated based on the radiation dose measured from outside a container (Paks).

－ If the nuclear materials cannot be removed entirely from a reactor, the remaining quantity must be measured or assessed (TMI-2).

VI. Policy on the Development of Technologies for Material Accounting － Development of Practical Management Technology －

As mentioned earlier, material accounting is essentially intended for the performance of nuclear material management by the nuclear facility operator itself. For this reason, the applied method must basically be practical enough to allow a facility operator to perform material accounting. Accordingly, the basic principle of minimizing obstructions to the main process of decommissioning and completing it in line with a decommissioning roadmap was adopted for the development of all technologies for the method of accounting for and controlling nuclear material in relation to fuel debris.

Importantly, development goals need to be provided in coordination with the regulatory authorities and the IAEA to ensure that no unnecessary goals for safeguards inspections are involved and avoid any overlapping efforts at a later period date.

Given that the technologies for measuring the quantity of nuclear materials can be used for the safeguards verification, development efforts must bear in mind their possible application in safeguards inspections (e.g., enabling inspectors to employ developed technologies). If the developed technologies are employed for safeguards verification, the decommissioning processes can possibly be reduced even further by performing measurements and verifications at the same time.

VII. Development of Technologies through International Cooperation

A practical development initiative was commenced through joint research after the signing of an agreement between the Japan Atomic Energy Agency (JAEA) and the National Nuclear Security Administration (NNSA) of the Department of Energy (DOE) of the United States on the safeguard technology for Fukushima Daiichi Nuclear Power Station in November 2012. The JAEA and TEPCO work in tandem to undertake development initiatives in Japan that are centered on this joint research. They also involve the Central Research Institute of Electric Power Industry (CRIEPI) and follow advice provided by the regulatory authorities and the IAEA.

The reasons for the adoption of such an approach are as follows.

Development of material accounting technologies by envisaging safeguarding methods

It is essential that material accounting technologies be developed while keeping in mind the safeguarding methods employed by the IAEA. The JAEA has extensive experience in the development of material accounting and safeguards systems for facilities that handle nuclear materials in bulk. For this reason, the JAEA understands the existing IAEA safeguards system and inspection methods that are employed at actual nuclear facilities. The development of suitable technologies that are practical and reasonable in cooperation with TEPCO is deemed possible.

Application of international findings

The NNSA of the DOE has a long history, extensive experience, and sufficient knowledge in relation to the development of technologies for measuring the quantity of nuclear materials for nuclear safeguards. The NNSA also keeps track of trends in safeguards of the IAEA, and their findings and experience are conducive to the development of suitable measurement technologies for implementing safeguards at the Fukushima Daiichi Nuclear Power Station. They have been working with the JAEA for over 30 years in the development of technologies for safeguards and the like.

Ensuring international transparency

Since the introduction of the Additional Protocol in the 1990s, more effective and streamlined IAEA safeguards have been pursued by, for example, introducing the integrated safeguards approach and the state-level safeguarding approach. One of the nationally led initiatives that have been implemented in response to the updated IAEA safeguards system is the enhancement of transparency in nuclear activities in the state. International collaboration in research and development, the publication of outcomes, and other efforts to enhance transparency in nuclear activities are expected to contribute to IAEA safeguards. The reliability of Japan's safeguards conclusions can probably be enhanced by demonstrating to the world the due consideration that the country has given to nuclear materials in molten fuel with respect to nuclear non-proliferation.

VIII. Current Status of the Development of Measurement Technologies

According to the current decommissioning roadmap (as of October 2014), the removal of fuel debris from Units 1 and 2 at the Fukushima Daiichi Nuclear Power Station is planned for 2020. In line with this roadmap, the development of the necessary method of accounting for and controlling nuclear material is underway in phases that last roughly every two years. From 2012 to 2014, studies have been conducted on nuclear material management methods and technologies that have been adopted in similar situations for measuring the quantity of nuclear materials in fuel debris. An evaluation of the feasibility of technologies for measuring the quantity of fuel debris will be conducted from 2014 to 2016, along with an exploration of a system concept for material accounting. The demonstration test (2016–2018) and production of the measurement system (2018–2019) are expected to be completed for the removal of debris in accordance with the decommissioning roadmap.

Nonetheless, the development of the measurement system must keep pace with the development of containers for the removed fuel debris and the removal method. For this reason, the need for a method of accounting for and controlling nuclear material has to be presented to various bodies, such as the group in charge of developing containers, to aid in the pursuit of an efficient design for the debris removal process.

As mentioned earlier, the findings from studies on similar accidents suggest that material accounting must be performed for removed fuel debris in units of containers. In addition, the performance of non-destructive measurements from outside the containers is deemed appropriate for the removed fuel debris to minimize the disruption to other basic decommissioning processes. With these implications in mind, the application of non-destructive measurement technologies for fuel debris in the Fukushima Daiichi Nuclear Power Station was evaluated by experts from the United States and Japan in terms of measurement costs, feasibility, measurement times and other factors that have an impact on the decommissioning process. To date, seven primary measurement technologies and 14 auxiliary measurement technologies have been selected. Basic research and development have been commenced for four of the seven primary technologies.

Going forward, a conceptual design will be developed for specific measurement devices that rely on these technologies, a performance evaluation will be conducted by means of simulations, and then a demonstration will be performed.

IX. Conclusions − Future Direction of the Project −

The important steps that need to be taken next include the development of a rational method of material accounting that takes into consideration transportation, storage, and other tasks related to the removed fuel debris. As the country that caused the most recent nuclear accident, Japan needs to demonstrate its sincerity to the international community by responsibly managing its nuclear materials.

Moreover, there are various possible ways that measurement technologies can be applied to the nuclear materials in fuel debris whose composition and shapes are hard to determine. We intend to pursue further development initiatives while keeping an eye out for such possibilities.

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Report

My Achievement and Future on My Hometown Minamisoma City Affected Fukushima NPP Accident to Cooperate with the Local Core for Reconstruction and Decrease Dose Rate in the Rice Fields

A Native of Minamisoma, **Osamu Amano**

The majority of Minamisoma City in Hamadori (an area located along the Pacific coast), Fukushima Prefecture, was not designated as an evacuation zone. With the exception of the younger generations, most residents have remained there with the aim of cleaning up and restoring their home communities. In this sense, Minamisoma City stands at the forefront of Japan's restoration efforts. However, the cleanup and restoration work would be precarious if the community members depended totally on the national, prefectural, and city governments. The author has sought to encourage local communities to take whatever action was feasible while discussing with them the most effective way of doing so. By making regular visits to Minamisoma City, where he has many relatives, the author has supported the local communities in collaboration with volunteers from Tokyo and local community members.

With his father and many other relatives still living there, the author visited his hometown for the abovementioned purpose in May 2011. Until September that year, efforts had been made to secure a partnership with the governments of the city of Minamisoma and the village of Iitate. Due to their slow response, a partnership was gradually established with JA Soma (an agricultural cooperative), the Minamisoma Decontamination Association (formed by youth volunteers from the Haramachi Chamber of Commerce), the Ota District Reconstruction Council, and the district leader of Jisabara.

The area relies mainly on agriculture, so soil plays an essential role there. The radioactivity concentration (Bq/kg) must be measured to assess the level of contamination and the extent of decontamination that is required. Since 2012, the author has been working with stakeholders and core members of the local communities to organize simplified measurements so that local residents can be updated on the radioactivity concentration in the soil. Ordinary radiation detectors (μSv/h) were provided free of charge at a soil measurement station run by the author's father, while lecture presentations, soil measurement days, and so forth were also held. Sunflowers, which hold promise as an effective means of decontamination, are about to bloom. In relation to this, the author also intends to work with supportive organizations to convey the views of Minamisoma residents to the Tokyo Electric Power Company, the city, prefectural, and national governments, as well as attentive observers from the rest of the world.

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I. Leaving the Restorative Work, Cleanup Initiatives, and Lifting of Evacuation Orders to Local Residents

Located along the warm Pacific coast of Fukushima, Hamadori has an idyllic climate. The people who live in this countryside area tend to be laid back and they seldom take action proactively. Nonetheless, the local wild horse chasing festival that is held every July serves as a reminder of the samurai horse riding training of days gone by. The samurai spirit lives on to this day.

If it retains a victim mentality, Hamadori will be left behind and suffer further ruin. Younger parents with children have already evacuated and they rarely return to visit the elderly who have stayed behind. As a result, families are disintegrating on a large scale.

Since his first visit to communities beyond the evacuation zones, the author has been yearning to encourage local initiatives to restore, clean up, and even further develop their own communities. The author also hopes to apply best practices wherever feasible in the current evacuation zones as a point of reference for the restoration and further building of their communities.

II. Motivating and Enabling Community Members Through Collaborative Efforts

Administrative staff lacking the necessary expertise or experts from outside the area would only draw resentment from local residents if they tried to reassure them of their safety. In particular, such an attempt would only prove counterproductive with the parents of children. However, since his father and relatives live there, the author is treated as a native expert from Minamisoma as an insider in each area. This local connection enables the author to provide local residents and administrations with a comprehensive explanation of the likely impact of radiation and realistic countermeasures without provoking a negative response. They even ask the author questions in order to consider the necessary measures together. His explanations have covered the causes of the Fukushima Nuclear Accident, the released radioactivity, the contamination and deposition mechanisms, and the decontamination and cleanup methods as well as descriptions of how radioactivity migrates to farm crops and how this migration can be restrained. The author briefed people residing in the Ota district of Minamisoma (where Ota Shrine holds the wild horse chasing festival) and the Tamano district of Soma (next to Ryozen). After that, the author and local residents conducted radioactivity measurements in their paddies and fields, scraped off the topsoil, and examined the effectiveness of deep ploughing to flip the top 30-cm layer of soil upside down (this approach involved a combination of lecture presentations, demonstrations, and joint measurements).

Gamma rays come from all directions 100 m away and they can affect measurements from 20 m away. Therefore, measurements must be conducted in a shielded environment in order to examine the effects of partial decontamination initiatives (e.g., deep ploughing of a 3 m square plot).

When the author and some local residents from the Baba district (closer to Namie) and the Ota district of Minamisoma organized demonstrations and measurements last August (2011), the author with a help of a few local partners covered the radiation detector with several blocks of lead. The detector and the shield had to be brought into the paddies before and after the deep ploughing. Unfortunately, these heavy blocks had to be carried one at a time. They are very unwieldy, especially given the poor footing in paddies. To resolve this issue, the author devised a cylindrical shielded container that can accommodate most types of commercially available radiation detectors and plastic storage containers for soil measurements. The author consulted Mr. Eiji Tadano from the Haramachi Chamber of Commerce about the idea of producing these cylindrical shielded containers locally, but the latter could not come up with any suitable local candidates. Consequently, the manufacturing work was requested of an ironworks in Osaka that Mr. Tadano knew. Made of led, the manufactured cylindrical shielded container could be moved around easily thanks to its external stainless steel carry handle. Several containers were ordered and received by stakeholders, thereby enabling them to conduct shielded measurements on site.

Today, cheaper containers are produced using scrap lead from a factory in the Ota district of Minamisoma that is operated by Mr. Teruo Ara, with whom the author works together as mentioned later. These containers are employed by JA Soma, Iitate, Tomioka, and many other places.

On-site demonstrations employ shovels, compact excavators, and other large machinery borrowed from local residents. This machinery is used to scrape off the topsoil or perform deep ploughing before the radiation dose of the soil is measured directly underneath a radiation detector protected inside a shielded container. Local residents are convinced when they see the radiation dose reduced to one-third, one-tenth or some other fraction of the initial level.

Unfortunately, a realistic approach such as this was not taken in the immediate aftermath of the accident that occurred in 2011. Initially, deep ploughing was not commonly practiced in highly contaminated areas due to the majority being in favor of scraping off the topsoil and taking it away to treatment facilities. However, the construction of these treatment facilities became difficult because many communities were reluctant to host them. A while later, a decontamination manual published by the Japanese Ministry of the Environment and another manual issued by the Fukushima prefectural government featured this practical approach demonstrated by the author as an option for decontamination.

In furtherance of these decontamination activities, the author would like to present a future plan that employs work logs based on his experience. Currently, the author is proposing that residents in contaminated areas request compensation from the national government and the utility company for the costs incurred in the conducting of deep ploughing, soil dressing, sunflower planting, and other types of work that they carry out themselves. Each resident can keep a work log to record the amount of labor, heavy machinery, and other forms of input that they require to carry out their work. These logs, which are examined and sealed by the leaders of the respective districts, can serve as the basis for requesting payments from the national government and the utility company. Under the work log system advocated by the author, local farmers can decontaminate their own farmland and even receive payments for the work. Farmers with ploughs and other heavy machinery can perform deep ploughing for other community members and then request reimbursement. In this way, the whole community can work together to decontaminate their farmland.

III. Mingling with People from the Jisabara District in Minamisoma and Iitate Who Were Introduced Through Relatives

1. Jisabara district, Minamisoma

Located in the mountains, Yagisawa Pass can be reached from Minamisoma via Prefectural Highway 12. Auntie Y, a maternal relative of the author, lives in the Jisabara district, where the trail to the pass begins. Traveling from Minamisoma, visitors can reach Iitate by passing through Yagisawa Pass. The Jisabara district borders Iitate. The current external dose rate (as of May 2012) measures somewhere in the range of 1.0 to 1.5 μSv/h. Last November, the author held a lecture presentation on the level of contamination in the district and potential decontamination methods. Thanks to generous support from JA Soma and the district leader, almost all of the district's residents gathered at the local meeting hall. The presentation gained their understanding. Later, two volunteers from Tokyo were invited to the home of Auntie Y to conduct an investigation on decontamination using deep ploughing, soil dressing, controlled burning, and the removal of garden shrubs. These two volunteers were Dr. Tetsuo Sawada (Assistant Professor at the Research Laboratory for Nuclear Reactors (present name: Laboratory for Advanced Nuclear Energy), Tokyo Institute of Technology) and Ms. Atsuko Kuroiwa (working for Mitsubishi Heavy Industries and a leading member of WIN-JAPAN).

The positively charged radioactive cesium that was produced in the accident adhered to soil, roofs, walls, and roads as well as to the trunks, branches, and leaves of trees. Radioactive cesium cannot be removed easily because its electric adsorption is firm and stable. However, its removal is possible as long as the media of adsorption can be moved somewhere else by, for example, scraping off the topsoil and cutting away trees and shrubs. Following the explanation that the author provided last November, the leader and local residents of the Jisabara district opted for the scientific and rational options. They decided where they should locate a temporary storage yard in their district. Due to the arrangements made by the city government of Minamisoma, the decontamination of houses and yards in that area is about to begin.

The city of Minamisoma canceled rice planting in all of its paddies in 2012 and it then plans to resume the planting in 2013. The author has been conducting a project involving the planting of sunflowers to decontaminate paddies and fields throughout the entire Jisabara district and other areas with highly contaminated soil. (The decontamination work is performed by removing the sunflower roots and stems after the plants have absorbed the radioactive cesium from the soil.) Local residents have planted sunflowers in paddies and fields with a total area of about 6 ha (totally 60 paddies and fields). The necessary seeds were provided by the Agriculture, Fisheries, and Forestry Department of the city government of Minamisoma. In a similar project conducted by the national government in 2011, the sunflower roots failed to remove radioactive substances that were still deposited on the soil surface. In 2012, however, over 300 farmers involved in the author's sunflower project will be requested to perform deep ploughing or other such operations to move the radioactive substances deeper underground before they begin sowing seeds from mid-May in an attempt to ensure that the radioactive substances are absorbed by the roots of the plants. These farmers represent not only the Jisabara district, but also other partner communities in the Ota district and Tamano in Soma.

Some have voiced the opinion that deep ploughing only disperses the contaminants. Nonetheless, in moderately contaminated areas, the soil contamination can be reduced from somewhere between 10,000 Bq/kg and 20,000 Bq/kg to 5,000 Bq/kg, a level that enables crops to be grown. At the same time, this process facilitates a reduction in the external dose rate.

Consequently, the dose rate among earthworms on the surface soil also drops, which translates into a reduced dose rate among wild birds and the small animals that feed on them. Deep ploughing is a realistic and scientifically sensible method for restoring a sound food chain. Extensive decontamination can be expected if sunflowers are planted to remove radioactive substances. Once the sunflower plants grow, their roots, stems, and flowers will be sampled to assess their effectiveness in removing radioactive substances.

Unfortunately, some paddies and fields have a soil depth of around 10 cm, which is not enough to allow topsoil scraping or deep ploughing. Auntie Y also has the same problem. The shallow soil lies on a hard gravel layer that cannot be upturned with a shovel. A large amount of soil would need to be transported from elsewhere to facilitate the necessary dressing (i.e., covering with uncontaminated soil), as explained in the manual published by the Ministry of the Environment. Test surveys are still underway in some areas, and these will need to be completed before a full-fledged decontamination operation can start. If the decontamination by sunflower planting is not effective, the remaining countermeasure for shallow paddies and fields is soil covering.

2. Iitate

Auntie K, another maternal relative of the author, has been supporting Mayor Norio Kanno of Iitate Village. Soon after the Fukushima Nuclear Accident, residents of one district after another evacuated the village due to the high dose rate that was observed despite its considerable distance from the accident site. Auntie K was separated from her family when she was evacuated to a temporary shelter in Matsukawa, Fukushima. In November 2011, the author worked with JA Soma to brief evacuees at the temporary shelter in Matsukawa on contamination situation and realistic cleanup methods. Personnel from the village office, local assembly members, and the mayor’s wife participated in the briefing and tried to initiate a decontamination process that would involve using deep ploughing and other methods. However, since villagers failed to reach an agreement and they were separated from their village, the author has failed to coordinate with them for any further action.

IV. The Bewildered Governments of Minamisoma and Iitate

On May 19 last year (2011), the author visited the mayor of Minamisoma to accompany Professor Satoru Tanaka, president of the Atomic Energy Society of Japan, and Dr. Tadashi Inoue, chairperson of the Cleanup Subcommittee. Every month from that June to September, the author visited the mayor and other senior city officials. Once, the author conducted a briefing for local residents in the gymnastic hall of an elementary school thanks to arrangements made by the city government.

The city mayor, Mr. Katsunobu Sakurai, is a friendly and smart person. The author has been briefing the mayor and senior officials of the city government on the nuclear accident and realistic measures. They understand the situation, but the government cannot take action alone. Decontamination work requires the right personnel. The downside of the area’s mild climate and laid-back culture is the limited availability of people who can implement transitional measures under abnormal conditions during an emergency. A decontamination measures office was established, but it is hard to imagine this office leading motivated city residents in a local decontamination initiative to restore the city with budgetary support from the national government, which is the author's hope. Despite the support provided earlier, the Minamisoma Decontamination Association has no realistic plans or executive capacity. They are unable to take coordinated action with the city government.

Until the accident that occurred on March 11, 2011, the village of Iitate had been trying to embody a "*madei* lifestyle," which is faithful to a local idiom that means devoting a great deal of care for people, under the leadership of Mayor Kanno. The community worked hard to cultivate healthy soil, and their farm products were shipped to the Greater Tokyo Area and even the Greater Osaka Area to provide a considerable income for the village. Each farmer has borrowed more than 50 million yen to purchase the farming equipment necessary to cultivate excellent soil. They will be left with huge debts if their products cannot be sold. The municipal government must take scientifically sensible measures while also taking into consideration these debts. At present, the village has divided opinions.

V. Partnerships with Core Community Members of Minamisoma and Other Concerned Municipalities, JA Soma, the Minamisoma Decontamination Association, and People from the Ota District

The author visited Minamisoma every month from May to December 2011 as well as in March and June 2012. With each trip lasting about three days, he regularly visited places such as JA Soma and the Ota and Jisabara districts.

1. JA Soma

The urban part of Minamisoma mainly consists of residential lots. However, farmland and forests can be found not far from the city center. Indeed, agriculture—particularly rice cultivation—is the key industry for Hamadori.

Serving Shinchi Village, Soma City, Minamisoma City, and Iitate Village as an agricultural cooperative, JA Soma is led by a charismatic president called Yoshishige Suzuki. The deputy director of the Rice and Grain Department, Mr. Yoichi Kikuchi, was kind enough to liaise with JA Soma and the leaders of the Jisabara district and Iitate and he helped the author to hold briefing sessions. He even photocopied and distributed the necessary handouts.

Mr. Suzuki repeatedly stressed the fact that their communities would fall apart if the farmers quit growing rice after receiving compensation payments. Motivated by the awareness shown by Mr. Suzuki, the author has been conducting lecture presentations, decontamination demonstrations, and measurements in an easy-to-understand manner. Senior staff from JA Soma met in a large meeting room to improve their knowledge and techniques. As a result, JA Soma became able to take scientifically sensible measurement, such as performing comprehensive rice inspections of the rice they ship with two NaI gamma-ray spectrometers they introduced.

In Minamisoma, the mayor, JA Soma, and other stakeholders agreed to give up cropping in 2012 in preparation for the full-fledged resumption of rice production beyond 2013. The goal is to grow rice throughout the entire area while limiting the radiation from rice to no more than 100 Bq/kg in accordance with the threshold set by the national government. To this end, Minamisoma will conduct cropping test in 2012 by doing decontamination in 200 paddies, including those with a high dose (Agriculture and Fisheries Department, Minamisoma City).

Decontamination is conducted using the following four methods.

(1) Topsoil scraping

(2) Ploughing

(3) Deep ploughing

(4) Application of zeolite and potassium in shallow paddies

Surveys consist of the following elements.

(1) Measurement of the radioactivity concentration in soil before decontamination work

(2) Measurement of the radioactivity concentration in soil after decontamination work as well as the radioactivity concentration of harvested brown rice

Full-fledged rice planting is planned for the next year based on the outcome of the surveys. One of the targets is to reduce the radiation level of soil to below 5,000 Bq/kg.

2. Minamisoma Decontamination Association

It is essential for measurements to be taken before and after the decontamination work. Indeed, proper decontamination is impossible unless the radiation levels are measured. Based on the knowledge and experiences as a licensed Category-1 Radiation Protection Supervisor, the author repeatedly conducted measurement workshops in his home region in October and December 2011 as well as in March and June 2012.

In order to achieve restoring, clean-up and lifting of evacuation order for the local area, youth volunteers from the Haramachi Chamber of Commerce, an organization that mobilizes the local industries and businesses of Minamisoma, were asked to offer their help in mobilizing the local industries and businesses of Minamisoma in efforts to organize lecture presentations, demonstrations, and measurement workshops. The taking of measurements requires practice and this skill cannot be mastered instantly in workshops alone. Unfortunately, the youth volunteers did not continue practicing. They set up the Minamisoma Decontamination Association, which was licensed by the prefectural governor of Fukushima. However, the association is not functional or competent enough to support any initiatives.

In a related matter, the second and subsequent measurement workshops were conducted in a large meeting room at the JA Soma head office so that personnel from the head office and four farming centers that serve five different areas, including Iitate (where people have been evacuated), could attend. The author helped participants to repeat the exercise of drawing calibration lines for soil measurements (correlation between Bq/kg and μSv/h) before measuring the radiation level of the sample soil that they brought with them. Personnel from these farming centers can now conduct soil measurements by themselves.

3. Ota District

Situated in the south of Minamisoma, the Ota district hosts the wild horse chasing festival at Ota Shrine. The people there exhibit a strong team spirit, just like the samurai of the olden days. The leaders of some districts and Mr. Kenro Okumura, a city council member from the Ota district, have set up the Ota District Reconstruction Council. Chaired by Mr. Kisao Watanabe, it is tasked with restoring the community from the damage inflicted by the tsunami and radioactive contamination. The author visited the district a few times to give lectures followed by demonstrations and joint performances of deep ploughing (i.e., flipping a 30-cm layer of soil upside down using a compact excavator), the removal of highly contaminated gravel, and soil dressing to shield the radiation at actual farmland and residential plots.

A closer partnership is being forged with volunteer musicians from a band called Rose in many Colors from Tokyo, who participated in the cultural festival held at the gymnastic hall of a junior high school in the Ota district last autumn (November 5, 2011). This March, an exchange session on initiatives for the Ota district was held by members of the Ota District Reconstruction Council and supporters of Tomioka. The team spirit demonstrated by the district should serve as a reference for Tomioka, Naraha, and Kawauchi.

VI. Approach to Affected Communities

The author would like to request that stakeholders in the nuclear sector remain mindful of the approach to affected communities.

Generally speaking, Americans tend to be more willing than Japanese to commit themselves to implementing initiatives.

The Fukushima Nuclear Accident directly involved the Tokyo Electric Power Company (TEPCO) and the national government (Nuclear and Industrial Safety Agency). However, anyone directly or indirectly involved in the nuclear power sector should be considered stakeholders in the accident. The author thinks that they should engage with the affected communities proactively with a sense of ownership. Unfortunately, the majority of people seem to stay on the sidelines.

People's failures sometimes cause problems for others. A person's qualities are demonstrated by how they react after causing a problem. The failure in Fukushima caused core meltdowns for just the third time in the world. The subsequent massive release of radioactive substances seriously affected many communities, and even caused family breakdowns. Such a blunder could perhaps be described as a devastating defeat in a war. The stakeholders must share the pain of the affected communities and engage in decontamination work as well as cleanup and restorative efforts with a sense of ownership. That is our responsibility. The stakeholders should visit the affected communities in person to support them. In discussions concerning the future use of nuclear energy, the actions that the national government, TEPCO, and other stakeholders have taken to help the victims will be called into question.

VII. Goals and Future Challenges in Relation to Providing Assistance From the Second Year Onward

The Japanese Ministry of Education, Culture, Sports, Science and Technology has conducted monitoring surveys alongside roads by using vehicle-mounted detectors. The measurements demonstrated a 30% drop in the external dose rate over the course of half a year. Of this drop, 17% can be accounted for by physical decay given that cesium-134 has a half-life of two years. The remaining 13% can be attributed to the self-cleansing effect of nature. This pace is five times faster than the global average. The topsoil there is carried away to rivers that almost resemble waterfalls in comparison to the much slower flows of the Danube and other rivers in Europe. After it reaches the sea bottom, the soil is further carried away into the vast ocean by swelling waves during typhoons or the like.

Spurred on by this natural reduction process, the author will collaborate with local residents to regularly monitor the soil in the affected communities and try to reduce the radiation level to 5,000 Bq/kg or less as a threshold for planting rice. Depending on the transfer factors for the intended vegetables and other crops, the radiation level of the soil needs to be further reduced or farmers will need to limit their choice of crops. The author and other stakeholders must communicate such information to the affected communities. The author is facilitating the establishment of privately owned simplified measurement stations (relative measurements taken using a standard sample identified with a germanium-based semiconductor detector) to supplement the public measurement stations (NaI gamma-ray spectrometers) prepared by the city government of Minamisoma.

More specifically the extent of soil contamination and the necessary decontamination efforts need to be assessed based on measurements of the radioactivity concentration in the soil (Bq/kg). Three systems for measuring the radioactivity concentration with ordinary detectors (μSv/h) were deployed at the homes of the author's father and two other relatives. Mr. Teruo Ara has installed another one himself in the Ota district. The author facilitates the taking of local measurements by preparing standard samples, publishing measurement instruction manuals, and conducting hands-on exercises. The measurement station that is run by the author's father free of charge was asked to measure soil from the paddies and fields of over 150 neighbors and other acquainted farmers. In addition to these measurements, the father also provides consultations for people who bring in highly contaminated soil. For instance, he recommends deep ploughing and provides advice on which vegetables can still be grown. The author receives the measurement results from his father via emails so that they can discuss together how the radiation level can be reduced. The father then passes along the advice personally to the owners of the relevant sample.

On June 2, volunteers of the Japanese Red Cross from Kashima, Minamisoma (led by Ms. Hideko Takano) held a lecture presentation on how radiation will affect local life along with an event at which the radioactivity of soil brought in by participants was measured. During the author's lecture presentation that was conducted at the community center in Minamisoma, Mr. Teruo Ara was joined by the author's father and relatives in measuring the radioactivity concentration of 70 soil samples brought in by 120 local women. The measurement results, which were obtained using a simplified system, were indicated on each bag. Most of the owners were relieved to find that the radiation levels were lower than they had expected. They were encouraged to grow summer vegetables and convinced that local products are safe to eat. Soil measurements will be continued by the author from the second year onward to provide people in Minamisoma and Soma with the necessary information and assistance.

VIII. Sharing the Experiences and Views of the Affected Communities with the Rest of the World

The world is carefully watching how communities affected by the Fukushima Nuclear Accident can be saved. The reason for this global attention is that Hamadori is a victim of the use of nuclear energy by humankind. The author is seeking to work closely with the affected communities to discuss what can be done and share our experiences with the rest of the world.

The Jisabara district in Minamisoma, the neighboring Ohara district, and Tamano in Soma (located further to the north) have all been contaminated, but the people living there have not been evacuated. The Jisabara district managed to designate a site for the temporary storage of soil from the district. The decontamination work is due to start with residential plots and houses. The decontamination of farmland is expected much later.

These communities are the victims of the use of nuclear power, and the world is keeping a curious eye on the way Japan handles this challenge. How do the residents of Minamisoma perceive the damage that they sustained in their respective communities (past)? What should be prioritized and what are their needs (present)? How do the communities and residents envision their future in ten to twenty years (future)? The author will work with local community members to share their thoughts with the government of Japan, the prefectural government of Fukushima, the city government of Minamisoma, and TEPCO as well as other concerned parties around the world.

The author will work with residents of the affected communities to grow sunflowers that will fully bloom from mid-July to early August. Every year, the author intends to conduct individual interviews with community members to record their feelings and thoughts, which he will then present in front of the sunflowers in full bloom. The author hopes that this message will reach TEPCO, the government of Minamisoma City, Fukushima Prefecture, and the people of Japan. To gain global support for our initiatives, the author also intends to translate this message into English so that it can be shared with the rest of the world at events such as the international conference to be held in Hiroshima this August by doctors around the world for the prevention of nuclear war.

The Perception Gap of Nuclear Energy between Public and Experts after the Fukushima Nuclear Power Plants' Accident

The University of Tokyo, **Hiroshi Kimura**

Since 2007, a special committee established by the Atomic Energy Society of Japan (AESJ) has been conducting a series of surveys of Greater Tokyo residents and AESJ members regarding their attitudes toward nuclear energy. The committee was assigned the task of developing and updating a database on media coverage and public opinion with respect to nuclear energy. This commentary refers to the survey results to explain changes in the perception gap between these two target groups before and after the Fukushima Daiichi nuclear accident.

I. Introduction

The 2011 Tohoku earthquake (also known as the Great East Japan earthquake) and tsunami that struck on March 11 affected nuclear power plants operated by the Japan Atomic Power Company (Tokai Daini), the Tokyo Electric Power Company (e.g., Fukushima Daiichi and Fukushima Daini), and the Tohoku Electric Power Company (Onagawa and Higashidori), as well as the Rokkasho Nuclear Fuel Reprocessing Facility operated by Japan Nuclear Fuel Limited. The accident that occurred at the Fukushima Daiichi Nuclear Power Station (hereinafter referred to as the "Fukushima nuclear accident") caused extensive damage, and this has most likely had a substantial impact on people's attitudes toward nuclear energy. The accident has presumably led to radical changes in the perception of nuclear experts, as well.

Since 2007, the Special Committee on Mass Media, which was established by the Atomic Energy Society of Japan (AESJ), has been conducting a series of surveys on Greater Tokyo residents and AESJ members regarding their attitudes toward nuclear energy. The committee has been assigned the task of developing and updating a database on media coverage and public opinion with respect to nuclear energy. The survey was also conducted in January 2012, about a year after the Fukushima nuclear accident. This commentary refers to the survey results to explain changes in the perception gap between these two target groups before and after the Fukushima Daiichi nuclear accident. After presenting what Greater Tokyo residents expect from the AESJ, the commentary discusses what roles the AESJ should play with due consideration given to the future relationship between the nuclear power and society as a whole.

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II. Surveys

Numerous surveys and studies have already been conducted to assess people's perceptions of nuclear energy quantitatively with a view to discussing the relationship between society and nuclear energy. These surveys and studies have identified the benefits, anxiety concerning nuclear power, and trust in electric power companies, the government, and workers at nuclear facilities as the key psychological factors [1). The perception gap between experts and non-experts is also an important issue when discussing whether nuclear energy is accepted or rejected by society.

Accordingly, in order to track changes in the perception gap between experts and non-experts over time, the Special Committee on Mass Media has been conducting a series of questionnaire surveys to measure these psychological factors among non-expert residents of the Greater Tokyo Area and experts affiliated with the AESJ. The first questionnaire survey on energy and nuclear power was conducted in January 2007. To date, these surveys have been conducted five times on Greater Tokyo residents and six times on AESJ members. **Table 1** summarizes the surveys conducted so far.

This commentary refers to surveys conducted on the two target groups at similar times from December 2008 onward (the second to fifth surveys for Greater Tokyo residents and the third to sixth surveys for AESJ members) to present information on the perception gap between them [2).

III. Perceptions of Nuclear Energy

This section presents information on how perceptions of nuclear energy before and after the Fukushima nuclear accident have changed among the two target groups (i.e., Greater Tokyo residents and AESJ members). The relative degree of interest in nuclear energy compared to other areas of concern is shown before two psychological factors that are

Table 1 Summary of surveys conducted

	Surveys of Greater Tokyo residents	Surveys of AESJ members
Target group	Residents within 30 km of the city center	AESJ members
Method	Questionnaires collected later from respondents assigned based on quota sampling	Survey sheets mailed to 1,400 randomly chosen members
Survey period	Round 1 May 2007 Round 2 Dec. 2008 Round 3 Jan. 2010 Round 4 Jan. 2011 Round 5 Jan. 2012	Round 1 Jan. 2007 Round 2 Jan. 2008 Round 3 Dec. 2008 Round 4 Jan. 2010 Round 5 Jan. 2011 Round 6 Jan. 2012
Responses (Response rate)	500	Round 1 559 (39.9%) Round 2 591 (42.2%) Round 3 611 (43.6%) Round 4 625 (44.6%) Round 5 624 (44.6%) Round 6 611 (43.6%)

considered influential in any assessment of the social acceptance of nuclear energy are discussed: “Use and benefits of nuclear power” and “Reassurance, safety, and trust.”

1. Interest in General Social Issues

Figure 1 shows the varying degrees of interest in general social issues according to the survey conducted on the two target groups in January 2012.

In January 2012, the Greater Tokyo residents who were surveyed tended to be interested in the following issues: “Natural disasters,” “Political and economic issues,” “Diseases,” “Accidents at nuclear facilities,” and “Global warming and other environmental issues.” Due to space limitations, the results of surveys conducted on non-experts before the Fukushima nuclear accident cannot be presented in this commentary, but interest in “Accidents at nuclear facilities” heightened after the accident. Respondents expressed even greater interested in “Natural disasters,” an issue that has always been their major concern. Similarly, they became notably more interested in “Radioactive waste” and “Nuclear energy.”

Meanwhile, AESJ members tended to be interested in issues such as the following: “Nuclear energy,” “Resources and energy,” “Science and technology,” “Political and economic issues,” “Accidents at nuclear facilities,” “Global warming and other environmental issues,” and “Radioactive waste.” Compared to the results for surveys conducted before the Fukushima nuclear accident, there was a rise in interest with respect to “Political and economic issues,” “Accidents at nuclear facilities,” and “Natural disasters.”

Somewhat similar trends can be noted for the two target groups before and after the Fukushima nuclear accident. The likely causes for this are the devastation caused by the 2011

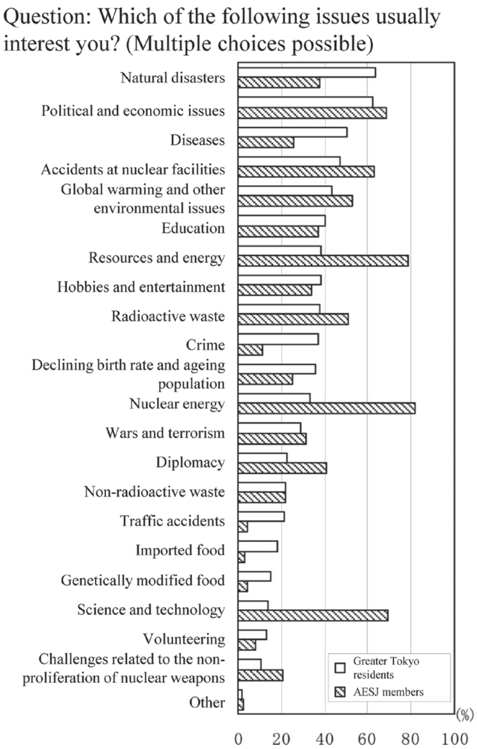

Figure 1 Interest in general social issues (January 2012)

Tohoku earthquake and tsunami, the subsequent Fukushima nuclear accident, and the political turbulence associated with these events.

A closer examination of the survey results for January 2012 indicates that, compared to AESJ members, Greater Tokyo residents tend to be less interested in "Nuclear energy," "Science and technology," and "Resources and energy." In contrast, AESJ members tend to be less interested in issues related to personal risk, such as "Diseases," "Crime," and "Traffic accidents." This tendency is probably attributable to the different social realities that they face.

2. Use and Benefits of Nuclear Power

Figure 2 compares the opinions that Greater Tokyo residents and AESJ members held with respect to the use of nuclear power before and after the Fukushima nuclear accident. Similarly, **Figure 3** compares the opinions of these target groups on possible alternatives to nuclear power, while **Figure 4** compares their opinions on the energy sources that they believe will account for the greatest share of power generation 20 years later from now. These results carry the implications described below.

First, the opinion of Greater Tokyo residents is summarized. A comparison of the surveys conducted before and after the Fukushima nuclear accident demonstrates that the number of Greater Tokyo residents who selected "Definitely continue using nuclear power" fell and that notably more of them chose "Definitely abandon nuclear power." However, many of them were undecided (in favor of continuing to use nuclear power: 20.6%; in favor of abandoning nuclear power: 48.8%; and no opinion: 30.4%). Furthermore, as shown in Figure 3, more people have come to recognize the alternatives to nuclear power. The perceived benefits of

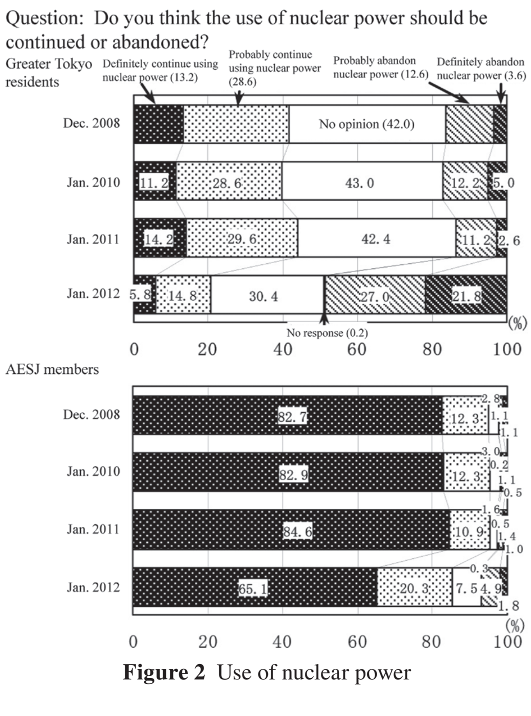

Figure 2 Use of nuclear power

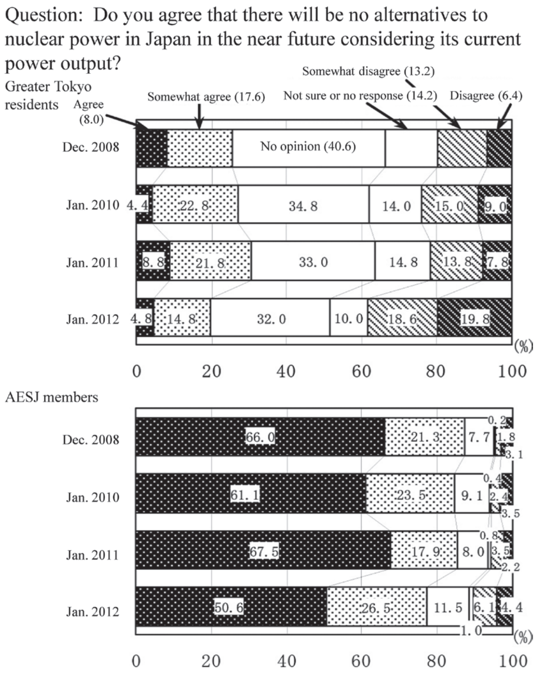

Figure 3 Possible alternatives to nuclear power

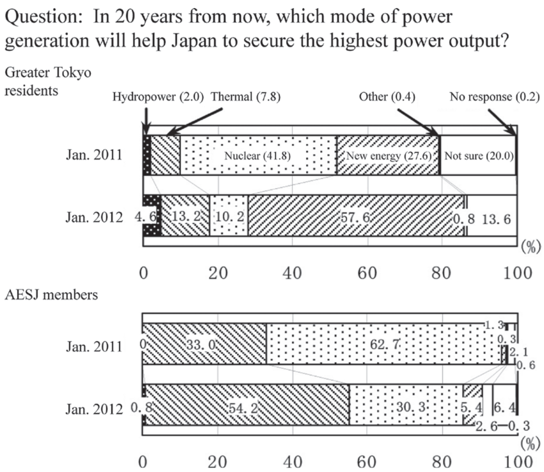

Figure 4 Mode of power generation with the highest output expected in 20 years later
* This question was added to the surveys conducted in January 2011 onward.

nuclear power in terms of issues such as curbing global warming and pursuing nuclear reprocessing to secure more energy have decreased.

In a related vein, greater expectations concerning new energy sources, such as solar, wind, and biomass energy, were observed in the survey results from January 2012. In fact, more than half of the respondents believed that a new source of energy would produce the highest power output in 20 years later (57.6%).

Meanwhile, the majority of AESJ members are in favor of continuing to use nuclear power even after the accident. They also recognize the benefits of nuclear power. However, this share has decreased from previous levels. Interestingly, the shares of experts who are ambivalent or inclined to abandon nuclear energy have increased slightly to 7.5% and 6.7%, respectively.

After the Fukushima nuclear accident, slightly fewer experts were convinced that there is no alternative to nuclear power. In earlier surveys, the majority of experts expected nuclear energy to produce the highest power output in 20 years later. In the survey conducted in January 2012, however, many more respondents believed that thermal power generation would do so instead.

A gap had already existed between the two target groups with respect to those in favor of continuing the use of nuclear power and those inclined to abandon it, but this gap seems to have widened since the Fukushima nuclear accident.

For both of the target groups in the survey conducted in January 2012, fewer respondents believed that nuclear energy would produce the highest power output in 20 years later. Nonetheless, these groups had a wide perception gap regarding possible alternatives to nuclear energy and the most significant source of energy in the future. Greater Tokyo residents had high expectations for new sources of energy, whereas AESJ members believed that thermal power generation would be the most viable alternative to nuclear energy.

3. Reassurance, Safety and Trust

Figure 5 shows the changing proportions of the two target groups in terms of whether they felt at ease or uneasy about nuclear power before and after the Fukushima nuclear accident.

Even before the accident, about half of Greater Tokyo residents felt uneasy about the use of nuclear energy. That proportion increased to 70.8% in January 2012 as the accident apparently

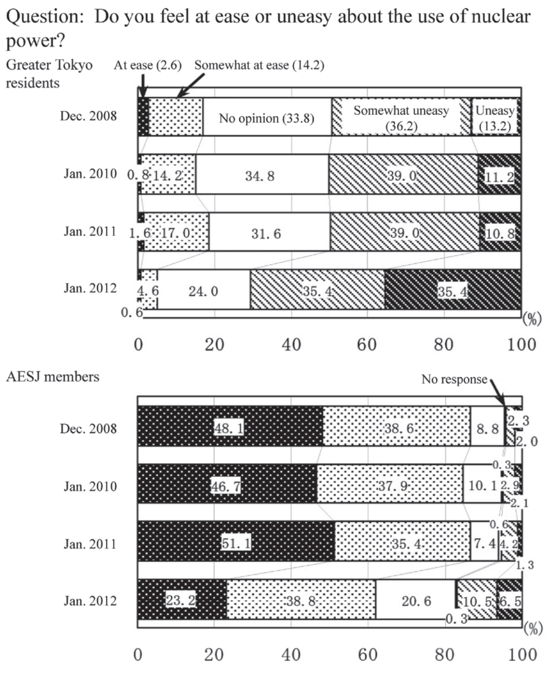

Figure 5 Sense of ease or unease about the use of nuclear power

alarmed people. Although specific questions related to safety are not covered in this figure, many residents already believed that nuclear power plants had become less safe after their extended operation and that they were vulnerable to earthquakes. According to the results of the survey conducted in 2012, even more residents believe this now. Residents who had been ambivalent about safety and hazards in response to specific survey questions before the Fukushima nuclear accident seem to have concluded that nuclear energy is dangerous now.

Compared to the results of surveys conducted prior to the Fukushima nuclear accident, the share of AESJ members who felt at ease about nuclear power dropped to about 60%. In earlier surveys, the majority of experts disagreed with the idea that the safety of a nuclear power plant decreases the longer it is in operation. This belief was reversed in January 2012. In addition, although most experts still denied the vulnerability of nuclear power plants to earthquakes, fewer did so in January 2012 than had been the case prior to that. Despite this, the perception gap between Greater Tokyo residents and AESJ members remains wide.

As shown by the top section of **Figure 6**, the number of Greater Tokyo residents that did not expect a nuclear accident like the one that occurred in Fukushima to happen (63.4%) far exceeded the number of those who did (25.8%). A similar yet more striking contrast can be seen between the 72.5% of AESJ members who did not expect such an accident to happen and the 18.6% who did.

The bottom section of Figure 6 shows the results of surveys conducted before the Fukushima nuclear accident with respect to a related question (i.e., the likelihood of a radioactive leak from a nuclear power plant involving civilian deaths in the next 100 years). The

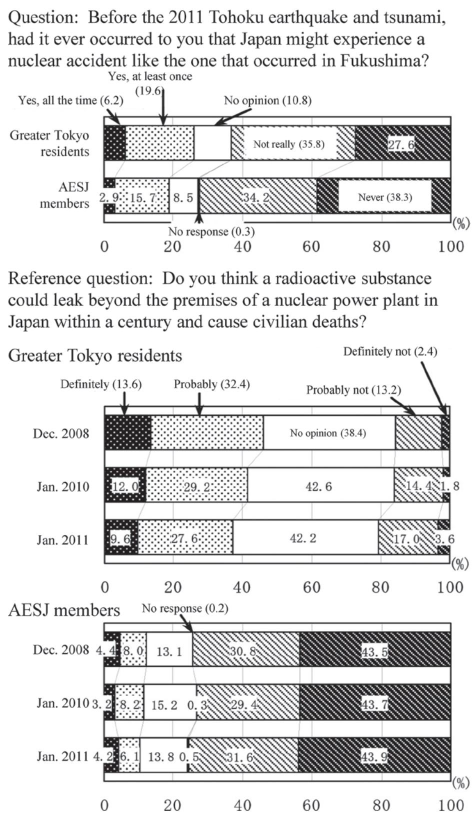

Figure 6 Likelihood of a severe nuclear accident

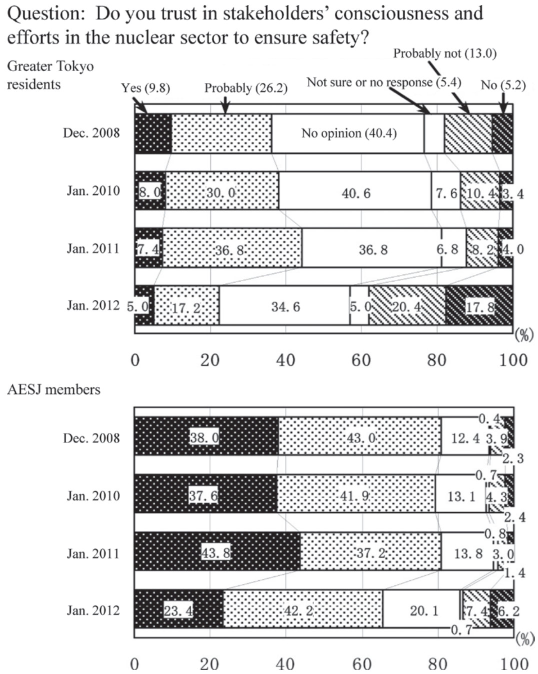

Figure 7 Confidence in consciousness and efforts to ensure nuclear safety

results here show that many Greater Tokyo residents believed that such an accident could occur, and this proportion was much bigger than the proportion of respondents who anticipated the Fukushima nuclear accident. Most likely, the residents could not realistically imagine a nuclear accident occurring before one actually happened in Fukushima, and their answers were based on a vague sense of anxiety. With this no longer being such an abstract concept, people responded with much clearer ideas in January 2012 after having experienced the Fukushima nuclear accident. In other words, the accident had a much greater impact on people's views than the vague possibilities that they had imagined earlier, which presumably explains why a large share of the respondents in January 2012 responded that they had never imagined such an accident could happen.

Similarly, many AESJ members responded that they had not anticipated the Fukushima nuclear accident. Indeed, the accident caught both target groups by surprise.

Figure 7 shows the extent to which both target groups trusted in stakeholders' consciousness and efforts in the nuclear sector to ensure safety. The survey conducted in January 2012 registered a decline in the proportion of Greater Tokyo residents who trusted the stakeholders, and this was combined with a considerable increase in the number of respondents who did not trust them. The gradual increase in public confidence that had been noted in previous surveys was abruptly reversed. Although the majority of AESJ members still maintained their trust even after the accident, the share declined.

4. Summary

The findings can be summarized as follows. The Fukushima nuclear accident sparked greater interest in nuclear energy among Greater Tokyo residents. They evidently became concerned about nuclear power, and this increased anxiety fed their mistrust of the nuclear industry.

Perceptions among AESJ members remained largely unchanged before and after the accident. Consequently, the perception gap between AESJ members and Greater Tokyo residents has widened somewhat. Nonetheless, AESJ members are also becoming uneasy about nuclear power, less confident about the nuclear industry, and slightly more inclined toward the abandonment of nuclear power. As such, perceptions among AESJ members need to be monitored carefully.

IV. Expected Roles of the AESJ

So, given the perceptions presented so far, what types of activities should be carried out by the AESJ? As a useful reference for discussing this question, **Figure 8** presents the roles that the two target groups expect the AESJ to play.

Greater Tokyo residents expect the AESJ to play a wide range of roles. For them, the top three priorities are to "Deliver accurate data," "Consolidate knowledge on nuclear technologies," and "Evaluate accidents and other such incidents." In contrast, although AESJ members expected the organization to "Disseminate knowledge and raise awareness," "Develop nuclear human resources," and "Transfer nuclear technologies," Greater Tokyo residents felt that these roles were less of a priority. How should these results be interpreted?

Having experienced the Fukushima nuclear accident, Greater Tokyo residents probably expect the AESJ to build up a system aimed at ensuring adequate responses to accidents. At present, they seem to expect the AESJ to play fewer roles in the long term, possibly because their minds have changed since the accident and they see fewer benefits from nuclear power.

The future of nuclear energy is hard to predict as it now depends on a policy choice by the

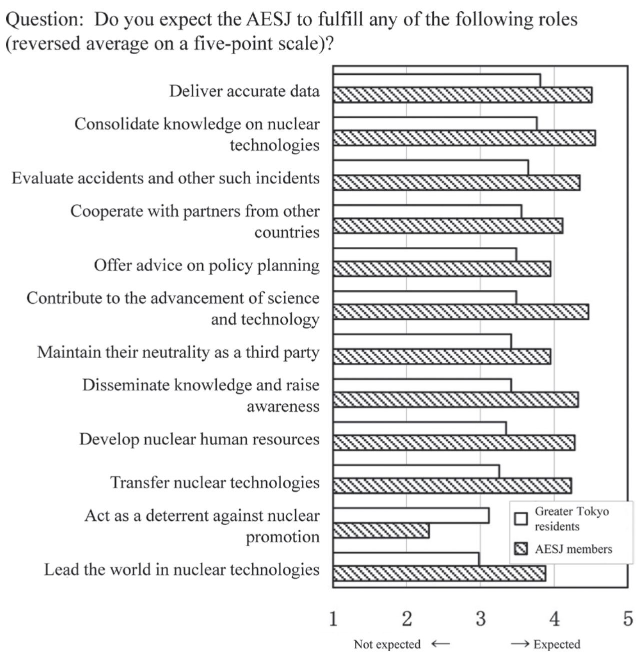

Figure 8 Roles expected of the AESJ (January 2012)

national government. Whatever the decision, it will take a long time to develop the necessary human resources and maintain adequate nuclear technologies. Certainly, the AESJ must build up its capacity to respond to accidents in line with the expectations of the people of Japan. In addition, the AESJ should probably look to the long term and clarify what needs to be done now, while continuously delivering appropriate information to the Japanese people about the role that it plays.

This commentary is based on studies that the Japan Nuclear Energy Safety Organization commissioned from fiscal 2005 to 2011 conducted by the special committee of the AESJ with the aim of developing and updating a database on media coverage and public opinion with respect to nuclear energy. The data obtained from these studies, including one on perceptions of nuclear safety regulations, have been published by the Social and Environmental Division on the AESJ website. To clarify any issues, please visit the website or contact the author (kimura@nuclear.jp).

On a final note, the author would like to express his gratitude to Mr. Shoji Tsuchida (Kansai University), Mr. Yoshihiko Shinoda (Wakasa Wan Energy Research Center), and the committee members for their generous support in designing and implementing these studies. He would also like to extend his appreciation to the many people and AESJ members who kindly responded to the surveys.

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Report

Lessons from the Fukushima Nuclear Power Accident

−Afterthoughts from Chairing the Investigation Committee−

Professor, Kogakuin University, Professor Emeritus,
The University of Tokyo, **Yotaro Hatamura**

Investigation and verification of the Fukushima Nuclear Power Plant Accident led the author to lessons for design engineers and the society as well. The essence of the accident is not just about what happened inside the plant but it also involves a large number of local residents evacuated from their homes and still cannot return due to the release of radioactivity. This paper reports the following aspects that we shall learn from this accident; verify the passage to success and to failure as well, plan in the inverse direction about what we need by hypothesizing what could happen, and understand the danger associated with nuclear power if we want to continue using it. My expectations towards nuclear engineers are also explained.

I. Introduction

The author accepted the government assignment to the Chair of the Investigation Committee on the Accident at the Fukushima Nuclear Power Plants (NPP). The committee published an interim report in December 2011, and the final report in July 2012 to conclude its investigation. The investigation revealed that the nuclear power industry's attitudes as well as preparation towards accidents were insufficient.

For example, thorough planning and preparation to the fullest extent possible for tsunami as well as earthquakes were necessary, however, the industry never conducted such preparation and ended up face this accident.

This paper reports, whether we will abandon nuclear power generation in the future or continue to use it, what we shall learn from this accident and what we expect for people in nuclear power engineering. Furthermore, my expectations towards nuclear engineers after this accident are also mentioned.

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II. Understanding the Accident

1. Sequence of Events at the NPP

The nuclear power plants faced events one after another and these events were just natural consequences that should have been foreseen.

On March 11, 2011, the Great East Japan Earthquake hit and Fukushima Daiichi NPP lost its external power source to the shaking. A series of tsunami followed the earthquake submerging the plant's switchboards and most of the emergency power sources. The nuclear reactors turned uncontrollable and accumulated decay heat within the reactor pressure vessels (RPV). Increase of the fuel rod temperature raised the temperature and pressure in the RPVs which then faced drops in the water levels.

The elevated fuel rod temperature caused reaction of the metal of fuel cladding tubes and water to release hydrogen gas that leaked into the reactor building and eventually triggered the hydrogen explosions (**Figure 1**). The RPV temperature, on the other hand, went up bringing the pressure up with it and caused RPV damage, then it released radioactivity into the containment vessel (CV). High temperature and pressure further damaged the CV releasing radioactivity to the outside. Many may have the impression that the hydrogen explosions spread large amounts of radioactivity, however in reality, the explosions contributed to a fewer amount compared the release through damages to the vessels.

Rise in the RPV temperature led to the CV temperature increase and the water-level sensors gave incorrect readings.

Lowered water levels exposed the fuel rods and γ-rays passed through the RPV walls into the CV. Elevated radioactivity in the CV hindered workers from opening the valves.

These unsurprising phenomena upon severe accidents should have been foreseen with planned counteractions, however, without such a priori measures, the operators could not see through the incorrect indicator of water-level sensors, and no remote mechanical operations were available.

2. Invisible Cloud of Radioactivity Arrived

Nuclear power disasters are not contained within the power plants. The influence of radioactive material when they are released and spread over a wide area extends for decades.

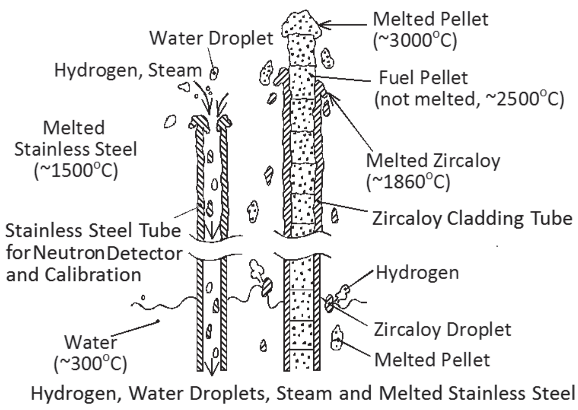

Figure 1 Illustration of phenomena inside RPV (Melted fuel rods led to hydrogen gas release and its escape to the outside of RPV)

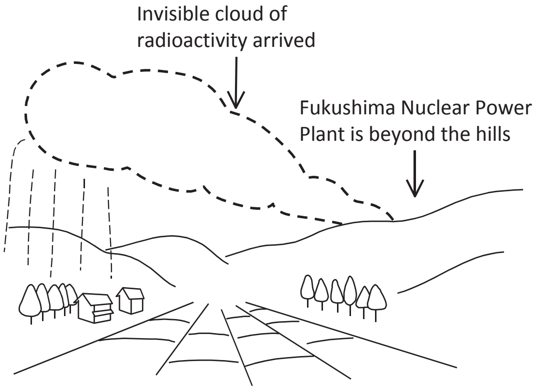

Figure 2 Cloud of radioactivity that reached Hiso area of Iitate-mura (Sketch by Hatamura based on hearings from local residents)

Figure 2 shows how the local residents perceived the arrival and fallout of the radioactive material. The author drew the sketch based on hearings from forced evacuees of Iitate-mura [1] who visited Hiso [2] district with the author. Invisible clouds of radioactivity arrived at the area and rain brought it down onto trees, buildings, land, and farmland. The fallout made the village uninhabitable.

We cannot fully understand nuclear power unless we look at what happens with radioactivity fallout from the viewpoint of the victims. Just the phenomena inside the power plants are not enough. For that purpose, we need to visit the location, see and feel the objects and talk with local residents (The author calls them the "three realities"). Secondhand information from those not directly involved or those quantitatively processed to an existing format will not let us accurately understand the situations.

III. What to Learn

Nuclear power is in fact attractive but at the same time involves great danger as energy, and the Fukushima NPP Accident taught us what we have to think about, prepare, and how to handle the technology. We need to thoroughly learn lessons from this accident.

1. Only Knowledge can be Passed On −Afterthoughts As the Chairperson−

The author listed 7 points in the last section of the report by the government investigation committee as thoughts by the Chair. My inauguration address stated, "The investigation shall withhold an evaluation by our next generation 100 years from now" because separate events, analyses, and summaries will be lost in the long run. The report[1)] puts together generalized knowledge at a higher level so people in the coming decades can make use of the knowledge from this accident to social situations and technologies of their times.

[1] Iitate-mura: "Mura" is one of the administrative districts "shi", "cho" (machi), "son" (mura), "ku" of Japan. The wider district "prefecture" (ken) consists of a number of shi, cho, son, and ku. There are 47 prefectures, like Tokyo, Osaka, or Fukushima, in Japan. Iitate-mura is 230 km^2 wide, with a population of 6,132 on March 1, 2011.

[2] Hiso: Hiso is the name of one of the sub-regions of Iitate-mura. A sub-region does not have administrative distinctions with others.

2. "Passage to Failure" and "Passage to Success"

In the midst of an accident we need to make choices, decide, and carry out the decisions. When the overall outcome failed, we can trace the "passage to failure" by connecting the choice at each stage of the entire process. On the other hand, there is a path that would have led to success if we had made different choices at these stages. This is the "passage to success" (**Figure 3**).

Most accident investigations proceed by analyzing only the sequences to failure, however, to make use of what we learn from the accident, we shall build hypotheses to clarify the knowledge of what selection or decision at each stage would have led to success.

Upon an emergency situation like an accident, we can only apply what we had planned earlier. We need to plan ahead of time what phenomena will take place and how to counter them and organize the analyses on the shelves in our heads. When the time comes to make choices and decide, it is impossible to build the logic one by one to make the right action in response to the process of events at the time. Each choice is made based only on what is visible at the time. Those in charge, therefore, have to understand that they are making judgments without the overall picture, and should always be ready to capture the overall picture at all time.

3. Learning from Other Industries

We learned the hard way from this accident that nuclear power technology has not yet gained enough experiences of failure as well as success; the technology is young and vulnerable.

The author concluded a hypothesis that "A specific technology takes 200 years to build enough failure experience" by reviewing the history of boilers, one of the core technologies since the industrial revolution. Invented in the 18th century, the boiler was established as a practical technology in the early 19th century, however, as its pressure increased, so did the number of accident victims. As a countermeasure, we set a number of safety regulations and with the development of new material and welding techniques, its safety gradually reached higher levels and American Society of Mechanical Engineers (ASME) lowered the factor of safety to 4 from 5 in 1942. Severe accidents with boilers have not occurred since then. ASME further, in 1998, lowered the factor from 4 to 3.5. The boiler took about 200 years to build

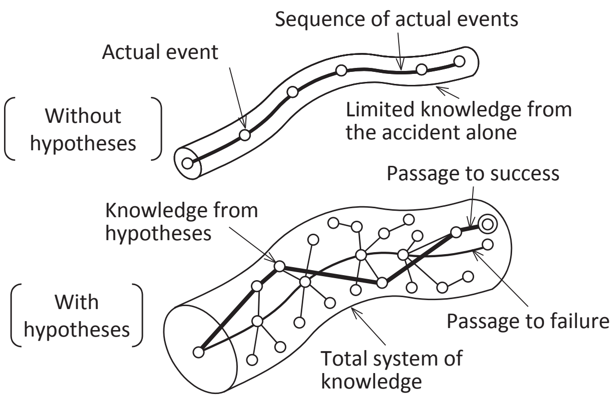

Figure 3 Adding hypotheses to the actual events of an accident leads to an enriched system of knowledge

enough experiences to reach today's state of safety.

Figure 4 shows this history of boiler technologies together with those of trains, automobiles, and airplanes.

The nuclear power industry, on the other hand, started its commercial operation around 1950 and today (2012), has reached only about 60 years of operation. There have been three severe accidents during these 60 years; Three Miles Island (1979), Chernobyl (1986), and Fukushima (2011). The direct causes of these three accidents respectively were human error, wrong design concept of a divergent system, and lack of preparedness towards natural disasters of earthquake and tsunami. Following the above hypothesis, the nuclear power industry still has 140 years to gain more experience of failures. The author believes that we can significantly shorten this learning period by making use of knowledge gained in other industries. To realize this accelerated learning, the nuclear power industry needs the modesty and flexibility to learn knowledge from other industries without being isolated. The industry should not build its own "nuclear village[3]."

Here is an example of knowledge, common in other industries, but not shared by those in the nuclear industry; With large size plants in the chemical engineering industry, emergency equipment like piping for fire extinguishing are never buried underground so leakages can be spotted. The Kashiwazaki-Kariwa NPP, however, had installed the piping underground and when the Mid Niigata Prefecture Earthquake in 2004 hit, they could not put out the fire that broke out in the voltage transformer facility because the piping broke under the ground. This is an example of not learning from common knowledge in other fields to worsen the already bad situation.

To shorten the 200-year learning period, those in the nuclear power industry need to widen their fields of view to learn not only from this accident but also from knowledge gained through accidents that took places in other industries as well as those that happened overseas.

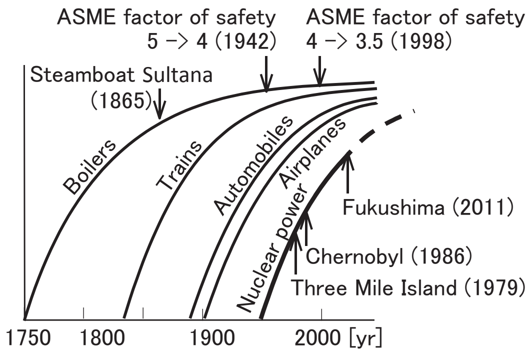

Figure 4 Any industry takes 200 years to gain enough experience of failures
–Nuclear Power is only 60 years old–

[3] Nuclear village: a cynical term to describe the closed circle of utility companies, manufacturers, government organizations, and academia that all claimed that nuclear power is safe. Although there has never been such a formal organization, the mass media blamed it to mislead people and themselves to believe the safety and necessity of nuclear power.

IV. What to Do Now

1. Countering the Radioactivity Contamination

The most serious fact with this accident is that radioactive material spread over a wide range affecting residents and the environment. The size of the affected area and the strength of radioactivity is not just a short-term issue. The influence will last for a longer period and we have to continue the counteraction for a long time.

We have to first acknowledge that we cannot extinguish radioactivity. The word “decontamination” may give the wrong impression that we can eliminate radioactivity with some sort of reaction like with the case of other chemical material. The reality is that we have to store the contaminated materials at some place where the effects is less, and only thing we can do is to wait until its radioactivity decays off.

The primary concern now is cesium-137. It has a half-life of 30 years and its influence will be negligible within 100 years. We need to store the contaminated materials until then. We cannot set a single or just a few large areas for storage, because of difficulty of securing such grounds. It will be most practical to dig storage holes in the fields and backyards to keep the contaminated materials in a number of small quantities (**Figure 5**). We shall build a long term plan so the area is fully resurrected 100 years from now.

2. Everything Changes and People’s Minds as well

Today, the mood for abandoning nuclear power generation is highly elevated in Japan. If we do abolish nuclear power generation, however, we cannot produce enough electrical power with just renewable energy and thus we have to import alternate fuel. The importing will not only lead us to higher electricity bills but it will also expose our vulnerability of relying on foreign countries for energy sources.

Making the judgment to abandon nuclear power now, on the other hand, may lead us to reaffirm the need of nuclear power within several decades. In the United States, for example, a new nuclear reactor was not built for 30 years after the Three Mile Island Accident, however, the higher need for nuclear power in recent years led to a decision to build new ones. This fact, when reflected upon a country like Japan with hardly any natural resources, may guide us to face the need for nuclear power again in the future.

The reason for selecting such a dangerous energy source of nuclear power was because the

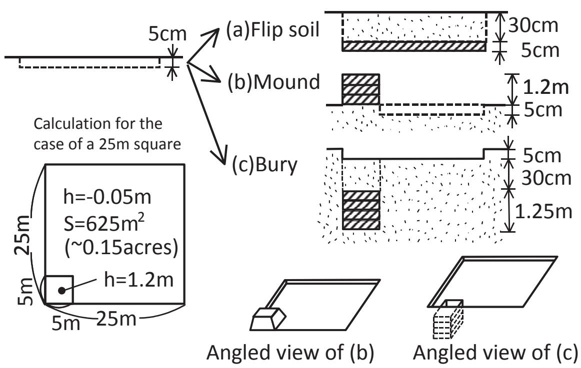

Figure 5 Practical handling of contaminated soil is mounding or burying

society as a whole was badly in need for electric power. As the economy turned active after the World-War II, the country faced an unprecedented demand for electricity, and the limited supply then was a constraint in expanding the economy and elevating the quality of people's lives. The decision to adopt nuclear power generation was made then to break the situation.

Before the nuclear industry started, the Kurobe dam construction started in 1956 and cost 51.3 billion JPY (twice the capitol of Kansai Electric Power Company then). The total power generation from Kurobe river power plant 4 was 340 MW that is even less than the Fukushima Daiichi Unit-1 power of 460 MW. The newest nuclear power plant in Japan has the capacity to generate about 1,300 MW a unit. This is about 4 times the capacity of Kurobe. It probably is not an exaggeration to say that our lives to freely use electricity without even thinking about the sources owes it to nuclear power generation. Whatever we conclude about the future of nuclear power, we shall not forget our history of the strong need for electricity we experienced in the past.

3. About Resuming Operations

We need to plan, not only about preventing disasters, but also about reducing their seriousness assuming accidents do happen. The myth that "nuclear power is safe" and the fact that many of us blindly believed it was in fact an abnormal state of the society. The Fukushima Daiichi NPP Accident taught us that for reducing the seriousness of accidents, the forward thinking of thorough planning and preparation to operate NPPs effectively and safely is insufficient. We must bear in our minds that we shall assume that accidents happen and we need the inverse thinking of what events will lead to severe accidents, what phenomena follows on, and how we can minimize the damage once they take place.

Up until the Fukushima Daiichi NPP Accident, the nuclear power industry was concerned with elevating the safety of nuclear power generation, of how to effectively and safely generate power and prevent accidents with regulations and rules. The accident, however, broke out anyway.

Nuclear power naturally has high energy density and thus is extremely dangerous. To deal with such a dangerous technology, "accident prevention" that is only concerned with how to prevent accidents is insufficient, and it is clear that we need to assume that accidents do happen and we shall plan ahead of time to the maximum extent possible about how to reduce the seriousness of disasters once they take place. We need to make the maximum efforts to prevent accidents, and at the same time, prepare "disaster reduction" plans to prevent the spread of damages and actually carry out emergency drills.

We have to say that evacuation triggered by the accident did not go smoothly. Futaba hospital, for example, evacuated patients that were not to be moved and the action turned into a tragedy of letting many of the patients die because of the evacuation. To prepare for evacuation, we must not only prepare plans and locations, but it is extremely important to organize evacuation drills with the participation of all residents. The 160,000 forced evacuees are still reporting anxiety about their unclear future. We need to be well prepared with long term plans to look after the evacuees from the time of evacuation until they recover their original lives back.

The stopped NPPs will be evaluated for restart once the stress tests to confirm safety prove acceptable. Restarting the NPPs with such a process is, however, questionable. There will always be oversights or areas that we fail to recognize (**Figure 6**). Without changing the basic thinking ways and just analyzing different phenomena or tightening the checking do not lead us to find missed points. The accident we faced this time was caused by tsunami that we

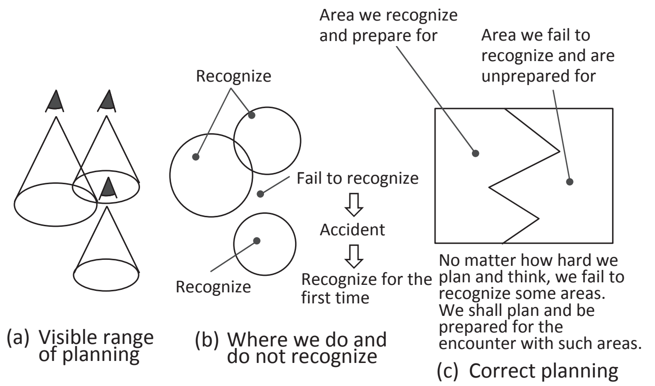

Figure 6 Despite our hard thinking, there remains areas that we fail to recognize

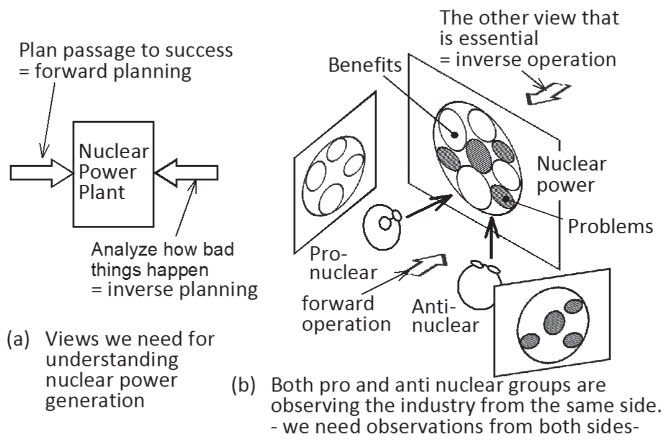

Figure 7 Visions needed for the coming nuclear power industry

failed to think about them. We should realize that starting from the assumption that we have no oversight would always lead to the cause of trouble in the future.

The discussion so far leads us to realize that what we need is to "in addition to how things can go well (forward planning), think how bad things happen (inverse planning)," by recognizing "what could happen do happen," in other words, assume that accidents do happen and analyze them in the inverse direction. This is probably the biggest lesson we learned from this accident (**Figure 7**).

To evaluate whether to restart the NPPs or not, we shall admit the dangers and conduct thorough discussions comparing such disadvantages with the convenience they produce.

V. Expectations towards People in Nuclear Engineering

After the Great East Japan Earthquake and subsequent tsunami waves crippled the cooling systems of the Tokyo Electric Power Company (TEPCO) owned Fukushima NPP on March 11, 2011, many specialists including employees from the utility company, regulating organizations, and academia frequently used the word "unexpected." Viewers developed the impression that they were trying to "escape responsibility saying it couldn't have been helped because they were unexpected." The people thought it was their responsibility to have prepared to prevent serious outcomes even with the great disaster this time because they have been operating under the safety myth that "nuclear power is safe."

1. Explain so People Can Understand −Information Announcements and Technical Explanation−

Upon this accident, a large number of information and technical commentaries were sent out to the society, however, we heard many complaints about the news and explanations. Information and explanations shall be given with the understanding of what the receivers are looking for, otherwise the intended contents will not reach them accurately. People tend to think they are "hiding" if the information does not reach the audience at the right time, and "lying" if the contents do not match the expectations. To avoid such misunderstanding, detailed information release in ways easy for the audience to understand is needed.

Also, information and technical explanations for this accident often included technical jargon and acronyms that were hard to follow without special knowledge of the field. The phrase, for example, "operated the valve manually" led many of us to imagine workers going out to the field to turn a handle attached to the valve. The fact in this case, was that the operator in the central control room manually turned a switch on the operation panel to send a signal to the control board that runs on DC power, and its output operated a solenoid valve to send compressed air to an air cylinder connected to a rack and pinion, beveled gear, or a linkage to rotate the butterfly valve. Many people, however, lack the knowledge of so many elements in this operation and from the phase "Manually operating the valve did not work" alone cannot image the precise picture of what happened. The person sending information shall accurately relay the meanings of technical terms and acronyms and at the same time arrange the information in ways easier for the audience to understand.

Today, all the Japanese need to have correct understanding of nuclear power and radioactivity, thus we expect proper information broadcasting from nuclear engineers.

2. Keeping the Technology Alive

This nuclear power accident was one of the worst failures in the history of human. We, however, should not handle it as if it is a taboo that we should not laid our hands on. Whether we stop using nuclear power or we restart it, we shall keep the related knowledge up to date to hold the nuclear power technology alive.

One reason is because we have to carry out the decommission processes of the Fukushima NPPs. Another is the fact that we will be left with the spent nuclear fuel even if we decide to abandon nuclear power. Furthermore, emerging and developing countries are eager to adopt nuclear power generation and even if Japan stops using nuclear power, it is questionable whether we should not carry with us the technology or not. To own the technology for exportation or not is another question. And as the former section explained, even if we decide not to restart the NPPs, it may be needed within several decades down the road.

To see progress in nuclear engineering, I expect those involved to not just reflect on the mistakes made but also to thoroughly study whatever they can from this accident and to keep developing it as one of the proper technologies. Unless those involved in the nuclear industry work with confidence and pride, it will be extremely unfortunate at least for the Japanese society.

I discussed afterthoughts of serving as the chair of the Investigation Committee on the Accident at Fukushima Nuclear Power Plants. I hope the people in the nuclear power industry understand my discussions and will make use of them.

Reference

1) Final Report, Investigation Committee on the Accident at Fukushima Nuclear Power Stations of Tokyo Electric Power Company, Medialand Works Pub., 2012.

Report of Community Dialog Forum for Residents of Fukushima Prefecture with ICRP on Returning Life to Normal in Areas Affected with Long Term Radiation from the Fukushima Nuclear Accident

−09:30−13:00 November 3, 2012, at Korasse Fukushima−

High Energy Accelerator Research Organization (KEK), **Masayoshi Kawai**

A dialog forum was held with residents of Fukushima Prefecture by the International Commission on Radiological Protection (ICRP) to discuss the recovery of life in areas affected by long-term radiation from the Fukushima Nuclear Power Plant Accident. The current circumstances and problems were presented by evacuees together with people involved in the media, the food industry, decontamination work, and so on. Concerns over radiation and a loss of trust in the government were voiced before solutions were discussed. Fukushima must share information proactively to dispel harmful rumors.

I. Introduction

With decontamination work underway, the Nakadori region in Fukushima Prefecture is finally regaining some stability one year and nine months after the accident occurred at the Fukushima Daiichi Nuclear Power Plants (NPP), which are operated by the Tokyo Electric Power Company (TEPCO). However, an undeniable gloom is cast by any monitoring post readings that exceed 0.23 μSv/h. Meanwhile, an article written by Kunio Yanagida with the title "Ignored Plight of Victims" was published in the *Shimotsuke Shimbun* (a local news paper) on August 15 of this year (2012). In the opening to the article, the author lamented having heard a story from a friend about a family he was acquainted with whose son wanted to get married to his girlfriend from Fukushima. His parents vehemently opposed the marriage and forced them to break up on the basis that she may have been exposed to radiation during her visit to her family home. About the same time, the president of a zealous environmental non-profit organization mentioned that marriage to women from Fukushima should be avoided. The frequent media coverage in opposition to the disposal of disaster debris within an extensive area made even the author—who became a resident of Fukushima from April that year—think that he should also speak up. The author had learned that the International

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Commission on Radiological Protection (ICRP), the moderator of three earlier dialog forums that were held in the prefecture after the accident, was going to organize another one in Fukushima mainly to discuss how to ensure that local voices would be heard. This commentary summarizes what the author heard at the meeting.

II. Dialog Forum

The program for the dialog forum is shown in **Table 1**. The forum convened 15 members of the ICRP, 11 speakers representing Fukushima Prefecture, 8 related government officials, 26 observers, and 10 personnel from the forum secretariat. ICRP members are from 11 countries, and hence the forum was highly international.

In his opening address, Director-General Toshinobu Sato of the Environmental Health Department represented the Ministry of the Environment as the forum organizer. He mentioned that the ministry had established the Radiation Health Management Office in line with the creation of the Nuclear Regulatory Authority in September that year. After Dr. Claire Cousins had given an address as chair of the ICRP Main Commission, Mr. Jacques Lochard began moderating the forum and explained how important it was for residents to participate in efforts to restore communities affected by radioactive contamination.

Table 1 Program of the dialog forum

9:00	Doors open
9:30	Meeting starts
09:30–09:35	Opening address Speaker: Mr. Toshinobu Sato, Radiation Health Management Councilor, Ministry of the Environment
09:35–09:40	Welcome address by the member representing the panel of experts Speaker: Dr. Claire Cousins, Chair, ICRP Main Commission
09:40–09:50	Topic: The importance of the involvement of residents in returning life to normal after an incident of radiation contamination Speaker: Mr. Jacques Lochard, Chair, ICRP Committee 4
09:50–10:30	Messages from Fukushima community members Message from the local media Mr. Masaya Hayakawa (*Fukushima Minpo (a local news media)*) Message from local residents Ms. Reiko Hachisuka (Okuma Town) Message from the local medical fraternity Dr. Toshiyuki Tsuchiya (Tsuchiya Hospital) Message from the decontamination team Mr. Masaru Moriya (Ministry of the Environment's Fukushima Decontamination Promotion Team)
10:30–10:45	Morning break
10:45–12:25	Roundtable discussion: Dialog between Fukushima residents, community members and the international experts Facilitator: Mr. Jacques Lochard, Chair, ICRP Committee 4 Information provided by: Mr. Katsuhiko Kikuchi (*Fukushima Minyu Shimbun (a local news media)*), Mr. Makoto Omori (TV-U Fukushima, Inc.), Ms. Mizuho Kajiwara (*The Asahi Shimbun(a major news media)*), Mr. Toshimatsu Sato (JA (Japan Agriculture Cooperation) Shin Fukushima), Mr. Takahiro Hanzawa (Date City), Mr. Shunkichi Nonaka (Co-op (a consumer cooperation group) Fukushima), Ms. Yuuko Sakita (NPO Genki Net), and Ms. Harumi Sato (Tomioka Town) Exchange of views between the roundtable discussion panel and audience on the floor
12:25–12:30	Final conclusion of roundtable discussion Speaker: Acad. Abel González, Vice-Chair, ICRP Main Commission
12:30	Meeting closes

The ICRP helps to introduce more effective radiological protection measures by holding direct dialog with those affected to listen to their concerns and expectations and assessing the local conditions. It encourages those affected to take heed of the lessons learned from Chernobyl, to conduct radiation monitoring, and to assess and understand their conditions in a common language with the aim of facilitating the implementation of a protection strategy and protective activities. Dialog forums, including the three other ones held in Fukushima, must be open to all people. The media are expected to report widely on these discussions. This forum stressed how important it is to ensure that local voices are heard. They quoted the following feedback from Ryoko Ando, who represented an Iwaki NGO called the Ethos of Fukushima: “After the nuclear accident, raging voices over Fukushima left behind those of us who live in Fukushima. Everybody wanted to have their say, disregarding what we think and feel. I could not accept that. I even felt angry. The reason why I started ETHOS in Fukushima comes from the conviction that it is we who should narrate our life. In the midst of the turmoil, ICRP111 was the only support for our mind.”

III. Voices from Fukushima

1. Message from the Local Media Mr. Masaya Hayakawa (Fukushima Minpo)

Fukushima has not made as much progress as that claimed by the ICRP in terms of decontamination, waste processing, radiological education, and health surveys. Residents of the prefecture have swayed slightly between a perceived sense of safety and danger. Local residents seem to have developed a certain degree of understanding about the basic idea of protection against radiation, but such reassurance has not allowed them to cast aside their concerns. In fact, some families cook separate meals for their children to reduce their radiological risks. In reality, scientific evidence concerning their safety has not reassured local residents. Furthermore, the ICRP was asked a question regarding an NHK broadcast on a Ukrainian government report that pointed out the radiological influence on health after the accident.

(In response, the ICRP endorsed a report issued by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) stating that the Chernobyl Accident has not been found to pose any radiological health risks to the local population, except for childhood thyroid cancer. Ukraine’s national team is a member of the UNSCEAR. The government of Ukraine has also endorsed this report.)

2. Message from Local Residents Ms. Reiko Hachisuka (Okuma Town)

Ms. Hachisuka is the president of the Okuma Chamber of Commerce. She does not know what to believe anymore as she struggles as an evacuee in Aizu-Wakamatsu. She has highlighted the government’s inadequate handling of the situation. Despite Okuma being the closest town to the Fukushima Daiichi NPP, no radiological education had ever been organized for local residents. It was only after the accident occurred that they began to hear unfamiliar terms like “millisievert” and “Becquerel.” Although the younger generations can access the necessary information through books or the Internet, members of the older generations who are unfamiliar with these tools tend to be out of touch with the latest information. Ms. Hachisuka even went to Ukraine and Belarus to hear about the accident that happened there. These visits led her to develop certain doubts, too. However, wherever she went, she was told that the protection of the health of children should be conducted with maximum efforts. She would like to hear information related to future hazards and health protection in plain language that is free of any jargon so that it can be understood clearly enough by elderly persons in their 70s and 80s. Whole-body counters and other such systems should be deployed in accessible places to facilitate quick testing. The forests in Ukraine and Belarus have not been decontaminated yet, but they are properly managed to prevent wildfires by clearing the underbrush. There must be an alternative for Fukushima, even if its forests cannot be decontaminated.

(In response, Mr. González commented that the Chernobyl Accident caused a greater amount of radioactivity across a wider area than the Fukushima Accident did. In the Chernobyl Accident, children suffered much greater internal exposure by drinking contaminated milk, so the radioactive impact of the two accidents is almost incomparable. In Fukushima, it is more practical to compare the local radiation levels with the exposure dose rate caused by natural radiation.)

3. Message from the Local Medical Fraternity Dr. Toshiyuki Tsuchiya (Tsuchiya Hospital)

The presentation covered how the medical systems of local medical associations worked after the Fukushima NPP Accident, many reflection points and their subsequent maintenance status, and the migration of healthcare practitioners out of Fukushima Prefecture. Dr. Tsuchiya had thought that things would somehow be managed during the confusion that prevailed in the immediate aftermath of the earthquake. However, the information on the disaster caused by the accident that he received after the earthquake far exceeded his expectations. In particular, the radiation exposure was completely unexpected. Worse still, all means of communication were lost. Local medical associations and institutions could not communicate through fixed and mobile phones, faxes, or the Internet. Unable to evacuate, patients were left stranded. It took three days before a rescue team from Japan's Self-Defense Force reached Futaba Hospital (in Okuma Town), and they only managed to evacuate about 30 of the 120 patients (total: 44 persons) there. The hospital arranged suitable destinations for these patients and somehow eventually managed to bring them to Iwaki on a chartered bus by taking a detour (through Minamisoma). During this evacuation, however, almost 20 patients lost their lives. The Fukushima Medical Association had developed a medical rescue plan in April 2006 for responding to accidents, but this plan did not work because the local medical associations and the integrated medical information system for the prefecture failed to collect information on sustained damage. Without any medical teams to coordinate the medical response, the rescue teams from the Emergency Response Headquarters in Fukushima Prefecture could only react to the on-site situation in a haphazard manner at best. Those people who were exposed to radiation and the medical practitioners responding to the accident had insufficient knowledge on what levels of contamination and doses would be dangerous. The three-tiered medical system was designed to provide initial and secondary radiation emergency care before offering further care at the National Institute of Radiological Sciences (NIRS). In reality, though, only the Fukushima Rosai Hospital and Iwaki Kyoritsu Hospital could handle the initial care. Fukushima Medical University and other institutions did not have anywhere near the necessary capacity. In light of this, a consensus was reached to assign roles as follows: Iwaki Kyoritsu Hospital and Fukushima Rosai Hospital would offer initial radiation emergency care; Fukushima Medical University would attend to severely injured persons who had been exposed to radiation; the NIRS would attend to more severe cases; and other hospitals, mainly in Iwaki, would offer other fine-tuned treatment. Another issue was the decreasing number of doctors available at hospitals, which had already fallen by 79 compared to March 1, 2011. This problem is particularly noticeable among promising junior doctors. Furthermore, almost 500 nurses have left Fukushima, a fact that contributes to harmful rumors.

(Dr. Cousins of the ICRP stated that education on medical measures implemented after the NPP Accident together with fundamental knowledge of radiation and radiation protection is required even among medical students as she suspects that few doctors around the world have even the knowledge of radiation and know-how required to respond to an accident.)

4. Message from the Decontamination Team Mr. Masaru Moriya (Ministry of the Environment's Fukushima Decontamination Promotion Team)

An explanation of the decontamination work was provided using a distribution map of radioactive contamination. In accordance with recommendations issued by the ICRP, the national government plans to conduct decontamination work in areas with an annual additional exposure dose that exceeds 20 mSv and evacuation zones within 20 km of the Fukushima Daiichi NPP to reduce the dose to 20 mSv/y or less. Municipalities plan to conduct decontamination work in other areas with a dose of no more than 20 mSv/y to reduce it to 10 mSv initially and then to no more than 1 mSv/y over the long term. Decontamination work is conducted according to the relevant guidelines published in December 2011. In accordance with the roadmap announced this January (2012), decontamination work will be focused on living areas, especially houses, surrounding farmland and forests as well as residential roads. Since the decontamination work will be conducted for houses and other private properties, Japanese law requires the provision of a pre-description to all residents, the acquisition of their consent on the dose measurement and decontamination work, and then the provision of a notification of the results. At the same time, procedures ranging from the provision of explanations concerning temporary decontamination waste storage spaces to the borrowing of such spaces are carried out (author's note: these processes are taking a particularly long time). The

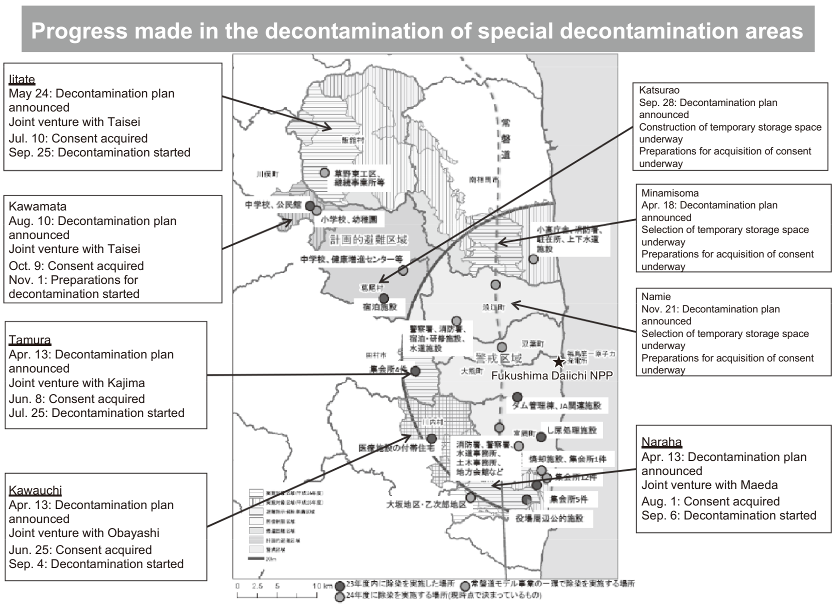

Figure 1 Progress made in decontamination of special decontamination areas by the national government

speaker explained the progress that has been made in relation to the decontamination efforts conducted directly by the national government in 11 municipalities. With the national government having established a decontamination plan for seven municipalities (Tamura, Naraha, Kawauchi, Iitate, Kawamata, Katsurao, and Minamisoma), consent is being sought in the five municipalities from Tamura to Kawamata and full-fledged decontamination work is underway in Tamura, Naraha, Kawauchi, and Iitate (author's note: later, Namie also announced a decontamination plan). **Figure 1** presents the progress that has been made in the decontamination work for the eight municipalities that have announced decontamination plans. Along with the target areas in each municipality for fiscal 2012 and 2013, the figure shows details such as the announcement date for the decontamination plan, the status of requests for consent, the start date for decontamination work, and the name of the contractor. The decontamination work on the Joban Expressway is scheduled for completion by the end of June next year (2013). In the pursuit of municipality-led decontamination work, 104 municipalities from eight prefectures with an annual additional exposure dose of 1 mSv or more were prioritized in the conducting of surveys. The presenter showed the names of 86 municipalities that discussed their decontamination plans with the national government. He pointed to the need for a faster pace in decontamination work, the decontamination and restoration of farmland, the decontamination of forests, enhanced decontamination and monitoring technologies, the exchange of information and findings on radiation risks, and coordination between decontamination work and infrastructure recovery. On a final note, he introduced the Decontamination Information Plaza, which is operated jointly by the prefectural government of Fukushima and the Ministry of the Environment. This plaza exhibits the progress that has been made in decontamination work and the technologies that are employed, shares information through its website and other means, dispatches experts to share knowledge on decontamination and radiation at workshops, and organizes various courses and briefing sessions.

IV. Roundtable Discussion: Dialog between Fukushima Residents, Community Members and International Experts

1. How Can We Find Out the Truth and Act Based on Reliable Information?

Sakita: Confusion seems to be caused by the inadequate way in which the government communicates with local residents. Even at briefing sessions for residents, the decontamination work promoters only provide information on matters that have already been decided. An agreement cannot be reached because residents feel that their voices are not being heard. The way things are managed must be changed. A common awareness of the issues must be shared throughout Japan as a whole to address misunderstandings and harmful rumors among people living outside Fukushima. Information must be shared to help them learn more about the situation in Fukushima.

Sato (H): The evacuation was ordered without any prior explanation. The first destination was Kawauchi, which had a population of 4,000, but entry was refused when as many as 16,000 residents of Tomioka flooded the village. While people were evacuating without any assistance, they were peremptorily ordered to undergo screening tests. They finally managed to settle in Iwaki. (Author's note: Discrimination against people exposed to radiation is undeniable after hearing about the manner in which this test was conducted and the fact that the authorities assigned rooms to segregate these people from evacuees from other low-contamination districts. Ms. Sato shared her understandable mistrust in the announcements made by the national and prefectural governments, considering they were forced to manage for themselves in total chaos.) Ms. Sato made the constructive comment that, in order to rebuild trust, genuinely trustworthy information should be provided at events held by organizations that residents can trust, such as the ICRP.

Nonaka: Co-op Fukushima has conducted measurements of the radiation doses of meals cooked by 100 households in the prefecture. It also conducts measurements of internal doses using whole-body counters and organizes study sessions on radiation. These activities convinced some evacuees on Ishigaki Island (Okinawa Prefecture) to return home. It is important for people to develop their own measure for radiation.

Hanzawa: Study sessions or other sorts of briefing sessions were repeatedly organized, thereby helping to build trust with community leaders. As a result, decisions on temporary storage yards could be entrusted to these leaders without the involvement of city government personnel. Instead of setting a one-size-fits-all standard, it is important to stress patiently that dose levels will be reduced as much as possible.

Sato (T): JA Shin Fukushima is conducting radiation inspections of food prior to shipment by using 45 NaI scintillation detectors and one germanium detector. In a period of seven months starting from April this year (2012), 24 t of food was disposed of after measurements had been conducted on 24,000 items. Most measured doses were below the detection limit of 20 Bq/kg. Only 38 of 5,460 peaches, a local specialty, carried a dose of between 20 and 50 Bq/kg. People in the prefecture are all concerned that an overreaction to Fukushima products with a dose rate exceeding the threshold may fuel a fear of these products. The safe adoption of these products for school meals will help to reassure people. The dose limit of 100 Bq/kg is too stringent for farmers and the food industry. The presenter shared his idea of allowing people to eat what they feel is sufficiently safe while introducing suitable shipping and intake restrictions. (The Swedish government initially set the dose limit for reindeer meat to 300 Bq/kg, the same as that for other food products. This limit was later raised to 1,500 Bq/kg in 1987 in consideration of reindeer-rearing farmers and the levels of meat contamination during nuclear tests conducted by the USSR when no limit was set. Moreover, the government decided not to preclude the consumption of meat with a dose of less than 10,000 Bq/kg among Sámi people in consideration of their unique dietary culture as long as their annual exposure doses do not exceed a specified limit. (author's note: *How Swedish Society Protects Itself from Radioactive Contamination* (in Swedish), translated by Sachiko Takami and Yoshihiro Sato)).

Omori: Data shows that the exposure doses in Fukushima were lower than the doses caused by the Chernobyl Accident by an order of two. The same is true for internal exposure. Media coverage prioritizes fairness, and the media never mentions whether the measured doses are safe enough. They convey only low dose levels in Fukushima and leave any judgment to the viewer. Radiation is always discussed from two opposing perspectives, which might be causing confusion among people. Moreover, news articles on any improvements made by the decontamination work are not published very often outside the prefecture. For the first time in two years, an elementary school in Fukushima was able to organize a sports festival this spring (2012). During our remote broadcast of the news, staff from the flagship station asked why we were not broadcasting images of kids wearing masks. I exploded and yelled at them. Local stations struggle with stereotypes such as this being imposed by their flagship stations.

Kikuchi: Although self-help and autonomy among residents and a participatory approach to decontamination plans and decontamination work are discussed, more tangible measures for involving local residents are required in order to stress the need for decontamination work. Decontamination work and food inspections are left solely in the hands of contractors, which leads to a sense of anxiety about the results. People would feel more convinced if they checked for radioactivity themselves. Consequently, creative measures are needed to provide parents with information that will allow them to learn how this can be done.

2. Dialog

Lochard: Despite all of the various different views, the situation on the ground must be steadily improved to ease concerns over radiation. Numbers and figures may serve as a guide for taking action, but ultimately what matters is how the landowners feel about their own situation. Just like Ms. Harumi Sato has done, it is important to go and meet people and obtain information through dialog and then take joint action to help each other. It is also important to send messages from Fukushima Prefecture to people outside the prefecture. (After this summary, the participants moved onto the following dialog.)

(Health effects of radiation exposure)

Menzel: The risk of 0.5% that is associated with 100 mSv means that a cancer rate of 40% without exposure will only rise to 40.5% after exposure to 100 mSv. This interpretation can be justified by evidence. The ICRP adopts a proportional model without a threshold for lower doses to be on the safe side. Exposure caused by the Fukushima Daiichi NPP Accident is added to natural radiation and medical exposure; it does not begin from zero.

Hachisuka: I am concerned about cysts being discovered among over 30% of young people from Fukushima Prefecture who underwent thyroid cancer tests.

Tsuchiya: Thyroids are unlikely to manifest an abnormality in such a short time even if they are exposed to a significant amount of radiation.

Niwa: Today's thyroid tests are so advanced that they can detect even tiny cysts, thereby raising the apparent detection rate. However, the cysts themselves are not considered abnormal, as they can be found among healthy people. Thyroid cancers develop slowly. The real impact can be assessed two years later and thereafter.

(Radiological education)

Sakita: No radiological education has been conducted in communities around the nuclear power plant and relevant information has not been provided to communities hosting evacuees. Information must be sorted and directed in a better way.

González: ICRP members are radiologists, scientists, and other experts in radiological protection. We cannot offer social advice. Instead, we help people obtain a deeper understanding based on scientific evidence.

Cousins: Today's dialog has taught us that advice and recommendations from the ICRP must be rephrased more clearly to make it easy for non-experts to understand.

Lochard: The ICRP analyzes issues from the scientific perspectives of experts with a diverse range of views. They offer their opinions as scientists, but some also propose actions. For instance, they can provide advice on what mothers could do to feel more reassured and how farmers could make sure that their products are safe enough.

3. Additional Comments

(Requests)

Nonaka: The victims of the Fukushima Daiichi NPP Accident are residents of this prefecture. Please understand that most mothers and evacuees who have not received sufficient compensation find it hard to accept explanations that are intended to convince people of the supposed safety of the local environment compared to, say, exposure during a flight on an aircraft between Tokyo and New York.

Sato (H): In the last thyroid inspection, cysts were identified in one-third of individuals. I would like the government to carry out enough nationwide studies to be able to determine if this problem is unique to Fukushima or common among people in that age bracket.

Hayakawa: I would like the ICRP to post their opinions concerning reports from Ukraine in the space designated for communication in Japanese.

Sato (H): The media are expected to report everything in a neutral manner rather than picking out remarks that suit the expectations of the media. The more local they are, the more they should endeavor to deliver information that will genuinely help the people of Fukushima.

Omori: As a person responsible for local media coverage, I always think about how I can do it properly to ensure that my reports do not cause any damage as a result, without building up the image of the evacuees required by the central media.

(How to ease concerns among mothers)

Sakita: Mothers are worried about the food that their families eat. Young women are worried about whether their future children may be affected. The correct information must be provided to address these questions. (Author's note: Mothers regret having caused their own children's exposure to radiation. They are constantly trying to avoid additional exposure. Anxiety over radiation is no doubt building up among them.)

Sato (H): Mothers in general do not have sufficient knowledge to be able to interpret the standards. It would be helpful to have some form of measure that would allow them to compare radiation doses from food before and after the accident.

Nonaka: An important step is the decontamination work. The Co-op holds study sessions on internal exposure to explain that a food intake of 70,000 Bq amounts to 1 mSv per year. With this relationship in mind, people can calculate that the intake of the 30 Bq contained in wild mushrooms amounts to 0.4 μSv per year (author's note: The correct figure is 45,000 Bq, not 70,000 Bq).

Hanzawa: People have gained more knowledge after the many rounds of briefing sessions that we have held, so they sometimes catch us by surprise with new questions. I believe people feel reassured if we provide the correct information as many times as necessary until they are convinced.

Sato (T): Mothers get extremely anxious if any abnormalities are found in their children during thyroid inspections. It is quite depressing to see many situations like this. The provision of appropriate support to worried mothers is vital. A conducive environment must be shaped to facilitate face-to-face communication among the many people who share the same circumstances. As an agricultural cooperative, we consider it is important to thoroughly measure radiation from our products and share relevant information about the fact that these products clear the radiation standard level for shipping.

Tsuchiya: I would like to acquire the knowledge and skills required to be able to provide proper answers to the various questions raised by many kinds of visitors.

Hachisuka: The national government should enact a new law for the issuance of special booklets for recording the healthcare of affected people. The owners of these booklets should be able to record their exposure doses as well as the exposure dates and places.

Omori: Briefing sessions for small groups of up to ten people should be held so that those who are more knowledgeable can offer explanations and advice to the other participants.

Kikuchi: Trust comes first before the gaining of any special knowledge. Newspapers need to regain the trust that they lost due to this accident.

Lochard: This dialog has shed light on some of the concerns held by the people of Fukushima. We will try our best to provide useful information to ease these concerns. The ICRP members will also discuss these matters. We look forward to making further progress together at the next meeting.

V. Conclusions

This was the first time the author participated in a dialog with the ICRP. It provided him with an opportunity to listen directly to the views of evacuees affected by the NPP Accident. Mistrust toward the government lingers as a result of matters such as the lack of information provided during the evacuation, the later controversies over radiation, the decontamination plans developed unilaterally by the government, and the delay to decontamination work. Various views were exchanged on how the trust of local residents could be regained. Some participants pointed out that the level of radioactive contamination in Fukushima is still low compared to that experienced during the Chernobyl Accident when graphite caught fire and even the nuclear fuel materials were released. Thanks to the progress that has been made in the decontamination work conducted in rice paddies and orchards, key crops such as rice, peaches and vegetables already satisfy the new standards for radioactively contaminated foods. Nonetheless, the mainstream media tend to push the expected image of affected communities. As a result, the views expressed by those from Fukushima seemed all the more important. Our most urgent task is to listen to the evacuees' needs and share information in the way that they intend. Since the cesium adsorbed in soil at Japanese farms is generally insoluble to water, the idea of scraping off a thicker layer of topsoil than usual will be applicable to the decontamination of rice paddies, so a non-profit organization is experimenting with this idea. The removed contaminated soil would then be stored underground in a large hole and covered by the uncontaminated soil that was obtained when the hole was dug. These ideas and other such efforts are expected to provide solutions to the decontamination of difficult-to-return zones, forests, and other highly contaminated areas while at the same time easing problems related to the need for temporary storage space. In order to adopt these ideas in the actual decontamination work, the support of local residents will be needed. The types of stakeholder dialogs that are commonly held in the West seem to provide an effective means of reaching consensus through frank and equal exchanges among the government, utility companies, and residents. The author hopes that the AESJ and its members will offer closer support to Fukushima and engage in nationwide risk communication concerning radiation to help dispel harmful rumors. It should be noted that the Fukushima Special Project established by the Cleanup Subcommittee of the AESJ cooperates with the Decontamination Information Plaza along with many other AESJ members who are registered as experts at the plaza. The website for the plaza (http://josen-plaza.env.go.jp/) posts decontamination updates. A video of this dialog forum can be accessed via the following URL: http://togetter.com/li/400999.

Commentary

What is the Background of Fukushima Daiichi Accident?

Japan Nuclear Safety Institute, **Toshiro Kitamura**

Two years after the Fukushima Daiichi Nuclear Accident, power companies are constructing tide embankments, reinforcing emergency power supplies, and implementing other necessary measures that are mainly intended to address the direct causes of the accident. The accident was aptly dubbed "a disaster made in Japan" by the chairperson of the National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission (NAIIC). The Fukushima Daiichi Nuclear Accident involves unique factors that are deeply rooted in Japanese society. In a sense, the accident is the ultimate outcome of various mistakes that were committed throughout the history of nuclear power development in this country.

I. Background Factors Leading to Fukushima Daiichi Nuclear Accident

1. Causes of the Accident

Gregory B. Jaczko, the former Chairman of the Nuclear Regulatory Commission (NRC), forthrightly pointed out that the Fukushima Daiichi Nuclear Accident resulted from its misguided design and siting. Allison M. Macfarlane, the current Chairman, went on to say that these mistakes had been neglected for years. In addition to their comments, the failure to respond quickly to external warnings must also be noted, especially bearing in mind that the Japan Atomic Power Company (JAPC) avoided severe accidents at the Tokai Daini Nuclear Power Plant thanks to the protective walls that they built in light of these warnings.

Both the national government and the Tokyo Electric Power Company (TEPCO) possessed information on the station blackouts experienced at nuclear power plants in other countries. They were also aware of the possible flooding of vital equipment in the event of a major tsunami. They did not scientifically preclude the occurrence of a tsunami on a scale that may happen once every thousand years. Nevertheless, TEPCO's management prioritized impending management issues over seemly unlikely tsunami hazards.

For some reason, they applied extremely irrational logic. The reason for this must be traced back through the history of nuclear power development in Japan.

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2. Reflecting on History

Japan's history of nuclear power development can be broken down into three phases, as shown in **Figure 1**, to identify the factors that led to the Fukushima Daiichi Nuclear Accident.

Phase 1: 1965–1978

Japan achieved spectacular economic growth due to its large-scale transition from agriculture to industry. During this period, people discovered the wonder of science and technology through developments such as the Shinkansen bullet train coming into service and the Apollo 11 mission being successfully completed. However, the negative consequences of such developments were put off to the next phase.

Politicians, bureaucrats, and industrial circles hastened to adopt nuclear power plants, which had just been put into commercial use in the West. Small-scale light-water reactors developed in the United States boasted a high output and excellent economic performance, but they were not designed for a small country that frequently experiences natural disasters. Japan did not have the capacity to assess the technologies involved, and design modifications are costly and time consuming. As a result, turn-key contracts were signed for the original designs.

Dr. Hideki Yukawa, one of the first members of the Atomic Energy Commission, resigned from his position in disgust at Japan's haste to operate commercial reactors that had been blindly imported from the United States without first verifying their safety while also neglecting to build up the country's own technical capacity based on original studies.

Japanese engineers assigned to work at American reactor manufacturers hungrily learned the relevant technologies. At the same time, they acquired the way of thinking that places great importance on rationality and economy. An increasing number of advocates were stressing the cost advantages of nuclear power. TEPCO's management reasoned that the Fukushima Daiichi Nuclear Power Plant should be sited at a lower altitude to minimize the amount of power consumed for water intake.

Japanese nuclear engineers from various different companies joined forces with JAPC to start operating the first light-water reactor at the Tsuruga Nuclear Power Plant. Soon afterward, TEPCO, the Kansai Electric Power Company (KEPCO), and other partners in this national project stopped loaning out their experts. These companies rushed to construct nuclear power plants in their own regions to begin generating power. However, due to a lack of

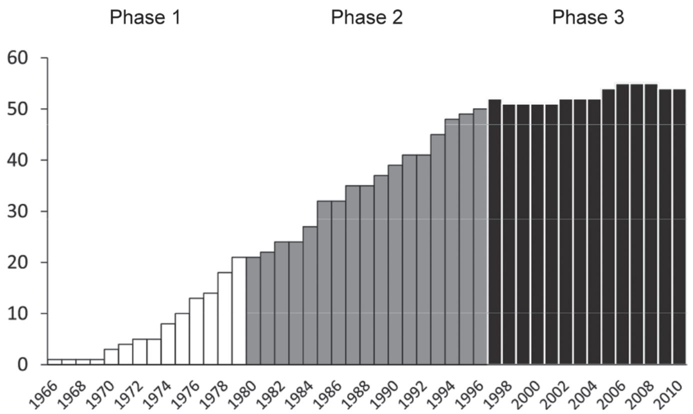

Figure 1 Number of nuclear power reactors in Japan

suitable knowledge on seismic mechanisms, aside from an understanding of the need for a solid bedrock, the plants were sited based mostly on the local population density, the optimal distance to a major power-consuming area, and other economic factors prioritized.

Once the power operations began, the focus was placed on fixing initial failures while the fundamental problems related to the design and siting of the plants ended up on the back burner. The proportion of nuclear physicists gradually declined in contrast to an increasing proportion of human resources with a background in mechanical engineering, electrical engineering, chemistry, and other such fields. Research on safety systems was deemed highly specialized.

Initially, members of the nuclear power departments at utility companies could engage in unfettered discussions without any constraints inherited from the past. However, once they began to assume the positions of presidents and vice-presidents at these companies, the nuclear power departments began to receive special treatment. In the absence of personnel exchanges with other departments, they began to foster their own corporate culture.

In accordance with national policy, the government left nuclear power plants in the hands of private utility companies, which cooperated with the government in return for generous assistance. Nuclear power development began to increasingly lack transparency for Japanese citizens.

In 1974, power source siting laws were enacted to facilitate the siting of power plants. Even after companies experienced blackouts due to lightning damage to a transmission line, a plague of jellyfish, and so forth, no consideration was given to the prevention of severe accidents. During this phase, stakeholders did not develop a sense of crisis because Japan was spared any major earthquakes and tsunamis.

Initially, the media lauded nuclear power as a dream source of energy. Host communities welcomed the construction of nuclear power plants and took pride in their participation in a great national project. They signed safety agreements with utility companies while trusting the national government and utility companies in relation to the risks associated with these power plants. Anti-nuclear movements were instead associated with the ulterior motives of particular groups. In 1974, a radiation leak from the nuclear powered freighter Mutsu was given widespread media coverage. The resultant harmful rumors made the nuclear power sector nervous about disclosures, so companies in this sector. They withdrew into their own comfort zone.

Phase 2: 1979–1996

The robust industrial growth that Japan enjoyed due to the manufacture of home appliance, cars, equipment, and so forth was fueled by an abundant and high-quality workforce, as well as cheap oil. With productivity rising due to rationalization, scale-ups, and mass production, the Japanese economy had reached its heyday. In the 1980s, the property bubble encouraged speculative investments and ostentatious consumption. Black Monday in 1987 proved to be a prelude to the bursting of Japan's economic bubble. The Gulf War and the dissolution of the Soviet Union were then followed by the 1995 Great Hanshin earthquake.

By then, Japan had 50 nuclear power reactors, the third largest number in the world. The operation of multiple reactors at the same site complicated their management. The two oil shocks had prompted the Japanese government to promote nuclear power strategically. In the shadows behind the country's glorified construction projects, discussion of the faulty designs that had been used for old nuclear power plants was made taboo. Meanwhile, stakeholders rushed to deal with the many accidents that occurred, and problems were experienced both in Japan and abroad. The Three Mile Island Accident that occurred in 1979 revealed the risks associated with light-water reactors. In contrast to the obligatory installation of various emergency power generators in the United States, Japan failed to implement appropriate emergency response measures and preventive measures in a timely manner. Instead, it downplayed the risks involved by insisting that a meltdown in the event of an accident would only have a minor impact on the environment.

In response to the Chernobyl Accident seven years later, the Japanese nuclear sector conducted a public relations campaign to stress that the reactors and social regimes of the two countries differed. Meanwhile, Japan began to lag behind the West in terms of measures for responding to severe accidents. In pursuit of ever greater capacity utilization, almost no provisions were made other than repeated stopgap measures. The risk of major accidents was downplayed.

The regulatory authorities were also reluctant to revise their safety standards. In fact, many problems were left unresolved. Examples of this include the compromised independence of the regulatory authorities, the inadequate quality and number of personnel, the excessive dependence on independent institutions, the inadequate awareness of responsibilities, the formalized disaster response drills that lacked substance, and the performance of inspections that depended heavily on documentation. During Phase 2, nuclear power plants in Japan remained untouched by major natural disasters.

The host communities eventually became more interested in the introduction of a nuclear fuel tax and other economic benefits as they gradually became oblivious to the risks of nuclear accidents. These municipalities added staff and bolstered their advisory commissions, and they signed more broad-ranging safety agreements. The absence of a proper legal basis became an impediment to the management of nuclear power. An anti-nuclear lawsuit filed against the national government pressed the government and utility companies to insist on sufficient safety at old nuclear power plants, but fundamental discussions on nuclear safety became a taboo.

During this period, the outsourcing of maintenance became standard practice. As a result, multi-tiered structures began to form according to the business affiliations of the manufacturers and utility companies. Retired employees and local community members found jobs within this network. This outsourcing hollowed out the technical capacity of the utility companies, and personnel became less able to deal with problems on site. This shift gave rise to a stagnant corporate culture. The utility companies became increasingly dependent on manufacturers and experts for technical support. Similarly, the regulatory authorities became dependent on the utility companies, with inappropriate relations between the two becoming the established norm.

Politicians, governments, utility companies, manufacturers, concerned organizations, host municipalities, and local business circles formed a system that secured their vested interests. Meanwhile, universities became dependent on the nuclear industry for employment opportunities for their students and research funds. The nuclear power departments of the utility companies lost their original free spirit, and management became increasingly precarious because bottom-up views could no longer freely reach the top. Generational changes in engineers crippled the transfer of expertise concerning old nuclear power plants. Despite the economic recession, labor-management cooperation pushed up wages among the utility companies. Enjoying top-class compensation packages, employees showed an increasingly conservative tilt. The executives of regulatory authorities frequently changed and no training programs were conducted. They ended up responding to accidents without having conducted a serious review of the existing system and regulatory revisions.

Phase 3: 1997−2012

The September 11 attacks shocked the world in 2001. A few years later, the financial crisis of 2008 triggered a global economic slowdown. Japanese economic growth stalled as China and other emerging economies began to close the gap on them. Rapid depopulation and ageing put both the national and local governments deeply in debt. After the Miyagi offshore earthquake and the Tokachi offshore earthquake, for the first time nuclear power plant in Japan was affected by the Niigata-Chuetsu offshore earthquake. In 1995, a sodium leak at the Monju reactor, which is managed by the Power Reactor and Nuclear Fuel Development Corporation (PNC), led to a scandal when the habitual covering up of problems was revealed. In 1999, the criticality accident that occurred at a nuclear fuel fabrication facility operated by JCO Co., Ltd. (JCO) caused deaths and forced the evacuation of local residents. The utility companies dismissed these problems as marginal accidents involving fuel production. Furthermore, they did not implement any measures for responding to severe accidents despite the criticality accidents that had already been experienced at nuclear power plants.

In 2002, repeated cover-ups, falsification and disguise incidents by the utility companies were uncovered. However, they avoided public criticism by replacing their top management while branding the problem as a safety culture matter. They did not attempt to investigate the root cause of the issue. Similarly, the regulatory authorities failed to deal with whistleblowing reports properly before the details were leaked. This blunder was inadequately investigated by the government and media.

A severe accident was barely avoided at the Mihama Nuclear Power Plant when its emergency core cooling system was activated and the piping for the secondary system of Unit 3 ruptured. Nonetheless, the regulatory authorities did not impose any regulatory requirements in terms of measures for responding to severe accidents. Instead, they simply encouraged the adoption of voluntary measures by power utilities. In 2007, the Kashiwazaki-Kariwa Nuclear Power Plant was affected by an earthquake. As a result, the power utilities focused their efforts on seismic reinforcement. Other than the decommissioning of two reactors at the Hamaoka Nuclear Power Plant, they failed to take adequate measures for tsunamis while stressing that the buildings at the Kashiwazaki-Kariwa plant had withstood ground motions twice as strong as expected. The power utilities made every effort to boost their flagging capacity utilization after a series of scandals and inadequate regulatory interventions. The National Institute of Advanced Industrial Science and Technology had warned of the risk that a tsunami comparable to the one triggered by the 869 Sanriku earthquake may occur. However, TEPCO procrastinated about the necessary response. The municipalities also failed to take any response as they were distracted by the idea of thermal neutron reactors fueled by plutonium. The national government and the utility companies did not incorporate any information on measures taken by other countries to address severe accidents. They were afraid of the potential impact on the ongoing anti-nuclear lawsuit, problems involving the provision of proper explanations to local communities, and a possible long-term shutdown. The idea of utilizing plutonium in thermal reactors emerged following the setback at the Monju reactor and the failure to complete a reprocessing plant. Spent fuel was subjected to interim storage.

The national government aspired to lead the world in the export of nuclear power plants to boost the country's energy security and curb global warming. It planned to encourage the gradual replacement of plants and drive the nuclear renaissance further. However, they neglected to take measures for responding to severe accidents and stem harmful practices in the nuclear sector. The host communities were heavily dependent on nuclear power plants for employment and other aspects of life. They were obsessed with the short-term benefits offered by additional reactors and the utilization of plutonium at thermal reactors. Due to concerns over global warming, nuclear power garnered unprecedented levels of public support.

No political efforts were made to address the issue of regulatory independence as pointed out by the IAEA. The regulatory authorities continued to rely on information from the utility companies, whose checks and balances were toothless at best. The utility companies formed cozy ties with their partner companies and local communities. The prevailing bureaucracy and blind observance of traditional approaches only favored vested interests. They gradually lost the ability to make radical changes to their policies. Furthermore, generational changes resulted in an inadequate transfer of technical skills to younger, less experienced engineers.

II. Mechanism and Impact of Emergence of Each Issue

Section I traced various factors behind the Fukushima Daiichi Nuclear Accident by reflecting on the history of nuclear power in Japan. Section II will look at these factors in terms of the issues involved to explain their emergence mechanism and impact.

1. Formalities

Formalities have constantly undermined nuclear safety. Disaster drills involving the local municipalities were simply performances that were choreographed according to the intended duration and availability of personnel. The media simply reported these events in a matter-of-fact way. Expecting such drills to raise awareness of potential hazards was unrealistic.

The Nuclear Safety Commission excluded risks associated with a long-term loss of external power without examining the on-site realities. Formal inspections, which were conducted by the regulatory authorities based mainly on documentation, overwhelmed the personnel in charge and endangered on-site safety.

After every accident, the leader of the host municipality would visit the nuclear plant to receive some media coverage as a performance for local residents.

The personnel working at the power plants did not even know how to operate the fire pumps, leaving the task to contractors instead. The operators had never undergone drills to cope with the potential loss of batteries and power supplies due to a tsunami. TEPCO took advantage of formalities to postpone any corrective actions based on the reasoning that the Japan Society of Civil Engineers had not officially recognized tsunami hazards. Formalities prevailed due to atrophied capacity, mannerisms, irresponsibility, complacency, lack of a sense of crisis, and prioritization of efficiency.

2. Betrayal of the Three Principles

Nuclear power has been advanced under a national policy led by bureaucrats and industrial circles, without the confirmation of public opinion. Nuclear power was never raised as an issue in national elections. This is contrary to the principle of democracy, which is one of the three principles for the peaceful use of nuclear energy. Moreover, nuclear power began with the use of imported technologies and regulations that imitated those used in the United States, which runs contrary to the principle of autonomy. Rather than following the principle of disclosure, the power utilities would cover up accidents while the regulatory authorities maintained a passive stance. Problems were usually revealed after the fact. Nuclear stakeholders had a shared sense of purpose in the development of this newfound energy for humankind.

This purpose bred elitism and cozy ties. They covered up difficult problems or just put them off. In this way, they lost touch with the public. Under the national policy being carried out by private companies, the stakeholders protected their own convenience and interests while at the same time mortgaging the future.

From the very beginning, the pros and cons of nuclear energy have been debated by proponents and opponents who have refused to recognize each other's existence. They have never sat down at the same table, even to discuss nuclear safety scientifically. They have stuck to their own conclusions by employing reasoning and collecting evidence in problematic ways. Inconvenient information has been trivialized or shelved. Discussions have been conducted only among likeminded groups. Proponents of nuclear energy have dismissed opponents as they deemed engaging them in discussion to be a waste of time. Opponents have filed lawsuits against the national government and other proponents. Such developments have trapped proponents within a myth of nuclear safety that precludes the proposal of additional safety measures.

3. Wrong Approach to Safety

The Fukushima Daiichi Nuclear Accident proved that the conventional approach to safety was wrong. Japanese people tend to pursue peace of mind (reassurance) rather than actual safety, whereas science and technology should always be pursued based on the reality of the situation. Given our monetary and workforce constraints, hazards should be removed according to their risk level based on the principle of safety management. Visitors to the Chalon Plant, operated by Areva, are not required to wear helmets. In Japan, however, helmets must be worn at sites ranging from an office building all the way through to the main control room. Japanese people prefer to avoid complicating rules, so they think that everyone should share the inconvenience of wearing helmets. This type of thinking is typical of agricultural people. Japanese people tend to believe that if something happens once it is safe to assume that it happens all the time. They are very particular about working from the ground up with a focus on details. However, they seem to mistake these costly, unfocused, and lukewarm inconveniences as robust safety measures. The West has tight regulations for responding to severe accidents and allows the power utilities to conduct quality assurance activities of their own initiative. The approach taken by Japan is the complete opposite. Accidents should be prevented by identifying unsafe conditions and securing a budget for the necessary measures. In Japan, people felt safe by raising awareness with slogans such as "safety first" and "safety culture."

All safety measures leave some residual risk. Nonetheless, fastidious Japanese people left themselves vulnerable by refusing to acknowledge this fact. The government and utility companies feared that the disclosure of any residual risk would be tantamount to recognizing the hazards posed by nuclear power plants. The ensuing attacks from opponents of nuclear energy would complicate court cases involving safety reviews. They avoided discussing residual risk to save the trouble of having to provide explanations to municipalities about disaster drills. Major accidents in Japan and other countries were evaluated, but any logical association with the hazards posed by other nuclear power plants in Japan was avoided. For instance, instead of finding commonalities with the Three Mile Island Accident, the Chernobyl Accident, and the criticality accident that occurred at a JCO Plant, the nuclear sector stressed differences in terms of the equipment, social regimes, rules, and quality of personnel. Attention should have been paid to the possibility that a light-water reactor may experience a severe accident, fundamental faults in the monitoring systems for reactors, key points in relation to responding to accidents, the magnitude of damage caused by the environmental release of radioactivity, and the dangers posed by the blind pursuit of economic performance. Stakeholders also misinterpreted the probability of once in 10,000 years as meaning “never in our lifetime.” They did not notice the danger of keeping three emergency power generators in the same place. Briefings to the public were simplified by consciously omitting any mention of exceptions and assumptions. Whistleblowers were shunned and a safety culture could not take root.

4. Cozy Ties

Stakeholders in the nuclear sector developed cozy ties amongst themselves, earning the nickname the “nuclear village.” Their objective was to realize ensuring energy security by adopting nuclear technologies. Power utilities enjoyed a solid financial footing thanks to their regional monopolies, so they could offer benefits and profitable transactions to their desired targets. Cozy ties were formed mainly among politicians, bureaucrats, utility companies, and manufacturers. They also extended to financial institutions, academics, the media, municipalities, labor unions, fishery cooperatives, and other interest groups. Eventually, the nuclear village added securing the interests of its members as the second goal. To protect these cozy ties, its members sometimes behaved immorally and violated the rules while ignoring the laws of physics, lessons from the past, and warnings from insiders and outsiders. Insiders fell prey to inflexibility as bureaucracy and secrecy prevailed. Critical thinking was discouraged. The village could no longer clean itself up because it had excluded anyone who challenged or criticized the collective will. Undesirable information was distorted to suppress the sense of urgency or kept in-house. Even when a problem was revealed, the village prioritized protecting its own vested interests and pursuing self-preservation. Measures were gradually implemented based on precedence to avoid rocking the boat. Indeed, the head of the regulatory authority symbolically remarked that it is best to leave well enough alone in response to the suggestion that the Japanese disaster management system should be aligned with practices applied in other countries.

5. Management Without Historical Perspective

At TEPCO, the nuclear power department wielded power independently to influence business decisions. Directors represented the interests of their respective departments. Meanwhile, the board of directors failed to make unified company-wide decisions. Instead, it just rubber-stamped what the departments wanted to do. Mr. Katsumata, the former chairman of TEPCO, explained in a press conference after the Fukushima Daiichi Nuclear Accident that they had adopted a management style of delegating tasks and responsibilities to the respective departments.

Responsibilities were also decentralized as TEPCO excessively outsourced the company’s core assignments. Their technical capacity was hollowed out, with their internal and external monitoring sections having been disempowered. They became fixated on their existing policies, plans, and past circumstances. Any solutions to fundamental problems were pushed aside. The company simply tried to ride out such problems by exploiting the political influence based on their economic power.

TEPCO’s top management should have had a firm historical perspective and been willing to rock the boat and break away from its prevailing inertia by squarely facing up to the series of problems that had arisen throughout the nuclear energy development. Top managers were chosen based on their ability to maintain the existing system and the policies of their predecessors. Radical reformers were excluded. Prime Minister Junichiro Koizumi publically avowed to smash the Liberal Democratic Party (LDP) in order to press ahead with postal reform. His historical perspective allowed him to predict correctly that the era of LDP-led majority governments, which had begun in 1955, would soon end. Upon his appointment as TEPCO president in 1993, Mr. Araki called for TEPCO to become a normal company with the aim of streamlining its management. However, he still failed to understand the historical background of the company's nuclear power department.

In France, the majority of the country's senior government officials and the top managers of major companies graduate from *grandes écoles*. Unlike the conveyor belt of students from Japanese universities as extensions of high schools, these selected few elites are trained to become well-rounded, cultured leaders who can consciously fulfill their vast potential for the benefit of society. Leaving aside its pros and cons, this traditional education system continues to produce the elites of French society. Japanese elites can tactfully assess a situation to avoid risks for their own organizations. They actively seek to expand their scope of authority, budgets, and staffing levels and secure plum jobs for their retirement. Utility companies indoctrinate their new employees to prioritize maintenance of the status quo. The factors that led to the Fukushima Daiichi Nuclear Accident demonstrate that nuclear energy was inadequately handled both by successive top management teams at TEPCO as well as bureaucrats from the Ministry of Economy, Trade and Industry and other government agencies that promoted nuclear energy as a national policy. They were only good at maintaining the status quo.

III. Conclusions

Society makes progress by learning from mistakes. We can learn lessons from the past only if we have a clear understanding of the reality of a situation. Such learning is also necessary to acquire an accurate understanding of issues that have been left unresolved and then stem potential problems resulting from past neglect. Japan can ill afford to continue using potentially hazardous nuclear energy if the measures that are taken in response to the Fukushima Daiichi Nuclear Accident are just stopgap ones that fail to address the root cause. New safety standards are being developed by the Nuclear Regulation Authority, but a more pressing task for our society is to build a solid foundation that will allow us to harness nuclear energy properly.

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Commentary

Developing "Practical Radiological Culture"
–A Proposal of "*Kizuna* Square" in Fukushima–

Japan Atomic Industrial Forum, **Yuko Wada, Seiichi Nakata** and **Takiko Fukumoto**

Belarus was severely affected by the Chernobyl Nuclear Accident. A few years later, the country established local information centers as places where local experts could actually conduct dose measurements with children and other members of the community while also performing other activities aimed at cultivating a practical radiological culture. These centers play a practical role in people's everyday lives. In Ukraine, an initiative has been introduced to provide psychological care.

Having conducted field studies to evaluate these activities, the Japan Atomic Industrial Forum (JAIF) concluded that similar initiatives led by "*kizuna* squares" (tentative name) might enable the municipalities and citizens of Fukushima to apply their radiological knowledge and feel safe enough to carry on their daily activities. The JAIF is proposing this idea while making sure that the squares can be autonomously operated according to the circumstances of each municipality and the particular needs of the community members. This commentary explains the intended purposes of *kizuna* squares and presents an initiative led by Mr. Sasaki, a teacher based in Koriyama, to provide a specific example.

I. Assistance Provided by the JAIF in Fukushima

The nuclear accident that occurred at the Fukushima Daiichi Nuclear Power Plant due to the 2011 Tohoku earthquake that struck on March 11 caused serious damage to local communities and wider society. The Japan Atomic Industrial Forum (JAIF) felt a keen sense of responsibility for having promoted nuclear power as part of the industrial world. Presenting a united front, the JAIF worked resolutely to provide aid to affected municipalities and community members with the aim of reconstructing Fukushima.

Representatives of the JAIF visited affected municipalities and evacuees from these areas to offer various forms of support that would meet their needs based on the outcome of a series of consultative meetings with municipal leaders and personnel in charge of disaster management and reconstruction efforts. Examples of this support include the provision of assistance to facilitate a better understanding of radiation, the establishment of venues that facilitate exchanges among municipalities, the collection of relief money and transfer of donations, and

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Figure 1 An activity being conducted to promote a deeper understanding of radiation

the presentation of case studies from other countries.

In particular, to facilitate a better understanding of radiation, the JAIF is assisting in the organization of studies and consultation sessions with experts in an effort to respond to the need for more information about radiation and its impact, as was directly requested during discussions with municipality personnel and community members (**Figure 1**). The JAIF is taking extra care to hold discussions in small groups of people sitting in a circle. It compiles practical Q&A documents in relation to everyday life in the relevant area and shares them with other municipalities.

During these activities, a vague sense of unease with respect to radiation has emerged as a possible reason for the slow progress in the decontamination work and the return of evacuees. Some evacuees are beginning to return to their home communities, but it has become clear that the younger generations are still staying away and that the infrastructure required by returnees has not been adequately prepared. To advance the reconstruction of Fukushima, the JAIF deemed it necessary to learn from the experience gained in relation to past nuclear accidents.

II. Initiatives in Belarus and Ukraine

The JAIF identified the experience gained through the response to the Chernobyl Nuclear Accident and the subsequent reconstruction efforts as a useful point of reference for the reconstruction of Fukushima. In December 2011, a team from the JAIF visited Belarus and Ukraine to conduct studies mainly focused on the socio-economic reconstruction process, the provision of healthcare for community members and the mitigation of the psychological impact of the accident, and the pursuit of a deeper understanding of radiation.

The following activities were initiated by local communities to address their own needs or sponsored by international agencies.

1. Local Information Centers (LICs)

–An initiative in Belarus

The team visited Chachersk in the Gomel Region, one of the areas in Belarus that were most heavily affected by the Chernobyl accident. The aim of this visit was to collect

Figure 2 An LIC established in a room at Zaleski Academy

information on how community members acquire information on radiation and how this information is applied in their daily lives. In Belarus, local information centers (LICs) have been established at schools and cultural facilities so that children and community members can get together easily. Zaleski Academy, a school for first to eleventh graders, also has a room dedicated for use as an LIC (**Figure 2**).

LICs have been established in affected areas since the 1990s to allow local experts to conduct dose measurements on children and community members. These centers are also intended to facilitate other activities aimed at cultivating a practical radiological culture, which could be interpreted as a practical application of knowledge on radiation in people's everyday lives. Today, there are more than 50 LICs in Belarus.

At Zaleski Academy, four teachers have been assigned to operate its LIC, which is equipped with various detectors for measuring radiation in foods, space and so on, cooking equipment, a laptop, a printer, and radiation-related learning aids and materials.

The pupils bring food and soil there to measure the radiation doses, check how the dose levels change after the food has been dried or cooked, and learn how food should be cooked to reduce the doses. Theoretical and practical lessons on radiation are conducted three times a week. In addition to gaining this knowledge, pupils also learn how to limit the radiological impact on their health in their everyday lives by measuring and checking the doses for themselves in the LIC. Moreover, the pupils share what they learn about radiation with their parents and other community members so that the rest of society can gain a deeper understanding of radiation.

2. Socio-Psychological Rehabilitation Centers

–An initiative in Ukraine

The team visited a socio-psychological rehabilitation center located in Korosten in Zhytomyr Province, one of the areas in Ukraine that were most heavily affected by the Chernobyl Nuclear Accident. The aim of these rehabilitation centers is to alleviate psychological stress among affected community members, mainly by helping affected children to gain a more accurate understanding of radiation. There are five such rehabilitation centers located throughout the country. Each rehabilitation center is staffed with not only psychological experts, but also teachers or experts of social studies, art, and physical education so that they can assist in the provision of art therapies, health monitoring, proper guidance on lifestyles,

Figure 3 An extracurricular activity being conducted for pupils at a socio-psychological rehabilitation center

and vocational training.

During the visit, on the day before Chernobyl Accident Liquidators Memory Day, pupils offered silent prayers and drew pictures dedicated to that day (**Figure 3**).

The centers organize extracurricular activities aimed at providing psychological care for pupils and develop radiological education programs for the relevant schools. They organize individual counseling sessions and workshops to alleviate the psychological stress suffered by community members. Psychologists, doctors, and social workers conduct training at the centers.

The affected communities experience psychological pressure due to their exposure to radiological contamination. Further initiatives are deemed necessary to allow those affected to move beyond rehabilitation and confidently build up their communities for a brighter future.

III. A Proposal for the Establishment of *Kizuna* Squares

–An initiative by the JAIF

During visits by the JAIF to affected communities in Fukushima, people shared the distress and concerns that they harbored in terms of everyday life. Earlier field studies of the initiatives adopted in Belarus and Ukraine inspired the JAIF to consider the idea of establishing *kizuna* squares (tentative name), which are modeled after LICs and rehabilitation centers, in the hope that they might help the affected citizens of Fukushima to apply their radiological knowledge and feel safe enough to carry on their daily activities.

The intended *kizuna* squares would combine the roles played by LICs and rehabilitation centers to promote a practical radiological culture (i.e., the practical application of knowledge on radiation on people's everyday lives) and to alleviate psychological stress, respectively. The JAIF plans to provide municipality personnel and community members with the support necessary for them to operate these squares autonomously by picking useful options according to their own needs.

The objective of *kizuna* squares is to serve as venues that facilitate mutual communication among community members to alleviate the psychological effects associated with anxiety and stress while at the same time helping them to acquire an accurate understanding of radiation and thus promoting a practical radiological culture.

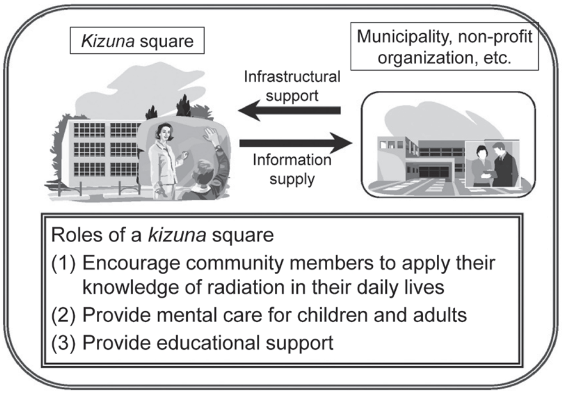

Figure 4 Concept behind kizuna squares

More specifically once they have been established in municipality offices, schools, town halls, and other gathering places, *kizuna* square could promote an understanding of radiation among wider society and serve as venues for communication (**Figure 4**).

The inputs that are required to establish a *kizuna* square include the following: radiation detectors, equipment for storing measurement data, personnel recruitment and training, a dedicated space, and funds.

The most vital element is personnel who will listen attentively to the concerns of local residents while providing them with accurate information on radiation. Our discussions with local residents revealed that they have lost trust in experts since the Fukushima Nuclear Accident occurred and are no longer sure who and what they can believe in. The presence of trustworthy personnel at each of the squares is vital to ensuring that local residents feel reassured and acquire accurate knowledge. Apt candidates for the position of *kizuna* square personnel would be people who are trusted in the local communities and close in distance to local people. Examples include (1) local officials (mainly for promoting a deeper understanding of radiation by conducting dose measurements on food); (2) teachers (mainly for conducting radiation-related educational activities and providing mental care for children); and (3) public health nurses (mainly for providing counseling support as well as medical and mental care).

A network should be forged among the *kizuna* square personnel, radiologists, sociologists, and other experts to give a boost to the activities performed by these personnel. Going forward, a network center will be needed to integrate the initiatives adopted by the respective *kizuna* squares.

It should be noted that “*kizuna* square” is only a tentative name. Each square should adopt a suitable name according to its local community and seek to serve as a familiar exchange venue extensively for local people.

IV. A Proposal for the Motomiya *Kizuna* Square

–An initiative developed by Mr. Kiyoshi Sasaki in Koriyama

As an example of a *kizuna* square developed by a teacher, this section describes radiation-related educational activities developed by Mr. Kiyoshi Sasaki, a teacher in Koriyama.

1. Radiation-Related Educational Activities

In the aftermath of the Fukushima Nuclear Accident, Mr. Sasaki felt that pupils urgently needed to gain an accurate understanding of radiation so that they would develop a rational wariness of it. Since September 2011, he has been conducting pupil-led radiological education at Meiken Junior High School in Koriyama. The aim of this is to enable pupils to measure radiation doses, analyze data, and make judgments for themselves as well as to work together to create initiatives.

Mr. Sasaki devised a plan for incorporating radiological education into the science curriculum taught at junior high schools by regarding 2011, when the Fukushima Nuclear Accident took place, as Year 1 of the radiological education program. Classes on radiation were conducted so that pupils could try taking dose measurements and creating their own models to acquire the skills necessary to measure doses, analyze data, and make scientific judgments. They were encouraged to engage in frank discussions based on scientific facts to cultivate their risk communication skills. After one lesson, a pupil took on a serious expression and said to Mr. Sasaki, "We will be facing the issue of radioactivity for a long time, and Fukushima must be reconstructed with our own hands."

In 2012, Year 2 of the radiological education program, Mr. Sasaki worked with his fellow science educators from other junior high schools in Koriyama and elsewhere throughout Japan to promote radiological education. A model experiment on decontamination was conducted to investigate how soil can shield radiation. First, variations in the air dose rate over the next year were estimated. After that, soil samples with a slightly high dose were packed in plastic bags and buried at progressively greater depths. The measurements taken on the surface demonstrated that the radiation doses were reduced to a half and a quarter for the bags buried at depths of 4 cm and 8 cm, respectively. This hands-on experiment helped pupils understand that their school grounds were sufficiently safe as they are covered with an approximately 50-cm layer of soil with a low radiation dose (**Figure 5**). Greater understanding among pupils was also sought through the adoption of team teaching, which involves school nurses explaining how radiation affects the human body and how we can protect ourselves from it. Pupils were convinced by the school nurses' explanation that the most important means of protecting ourselves from radiation is our immunity, which should be boosted by a balanced diet, adequate sleep and rest, and moderate exercise.

In April 2013, Mr. Sasaki was transferred to Koriyama Sixth Junior High School in Koriyama. In Year 3, he plans to continue this radiological education program with a focus on

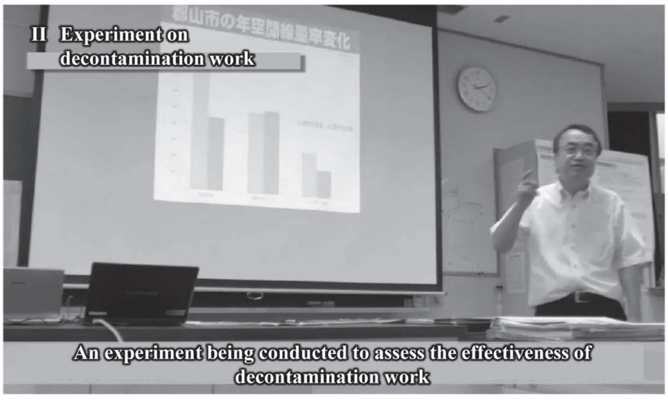

Figure 5 Mr. Sasaki conducting a lesson on radiation

autonomous learning.

2. An Initiative for Motomiya *Kizuna* Square

In July 2012, Mr. Sasaki visited Ukraine and Russia to seek further inspiration for his radiological education program in schools. During his visit, he became interested in the socio-psychological rehabilitation centers in Ukraine. Later, he supported the idea of the JAIF establishing *kizuna* squares. As a model project, he launched the idea of establishing Motomiya *Kizuna* Square to help children return to a more spiritually rich lifestyle. Motomiya is located about 60 km from the Fukushima Daiichi Nuclear Power Plant, so citizens are concerned and worried about the health effects of radiation. Local agriculture, fisheries, forestry, tourism, commerce, and other industries have been hit hard by harmful rumors.

Seven activities have been proposed for Motomiya *Kizuna* Square: (1) the provision of constant support by three resident personnel; (2) the collection of local information; (3) the running of mental care workshops; (4) the conducting of local awareness activities; (5) the promotion of radiological education; (6) the provision of integrated information; and (7) the promotion of study groups.

The personnel required include the following: (A) a radiation measurement officer (one resident staff member from the city office); (B) an intelligence and information officer (one resident staff member from the city office); (C) a mental care counselor (one resident staff member who is a local doctor or counselor); (D) radiation education facilitators (a few persons who are local teachers or NPO staff); and (E) community supporters (a few persons who are neighborhood association leaders or social workers). The idea is to hold monthly consultative meetings attended by all of the personnel involved in the *kizuna* square along with network conferences to be held as necessary for information exchanges and training (**Figure 6**).

In March 2013, Mr. Sasaki presented his idea of Motomiya *Kizuna* Square at a training session organized by the Adachi Liaison Sub-Council of the Municipal Education Board for Fukushima Prefecture. He plans to encourage Motomiya and the neighboring cities of Nihonmatsu and Otama (formerly known as Adachi district) to establish Motomiya *Kizuna* Square as a means of helping children to understand radiation and ensuring their sound mental development.

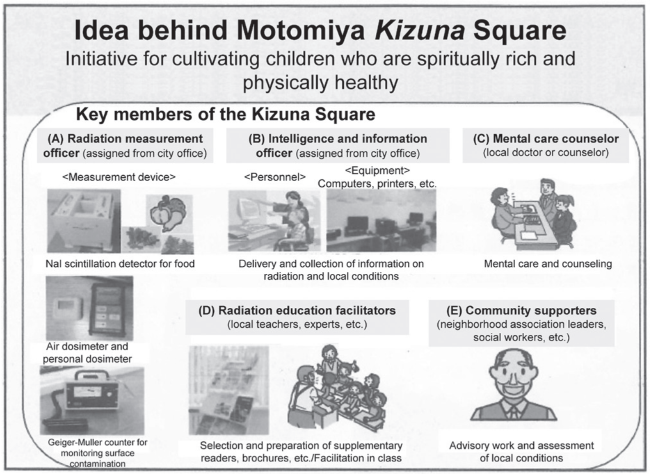

Figure 6 Idea behind Motomiya *Kizuna* Square

His initiative was initially driven by a desire to find out what was happening during the Fukushima Nuclear Accident. Later, his perceived need for pupils to acquire accurate knowledge on radiation so that they could make their own judgements led him to conduct radiation measurements, perform model decontamination experiments, and give lectures on the radiological health impact. He continues to work on the idea of Motomiya *Kizuna* Square because he is worried about the effects that prolonged evacuation will have on children. He believes that they need to be provided with mental care to avoid them falling into delinquency.

V. Conclusions

Many of the people affected by the Fukushima Nuclear Accident continue to lead difficult lives as evacuees or live in radioactively contaminated environments. Stakeholders in the nuclear sector have a responsibility to provide support to the people of Fukushima, especially given their earlier cooperation in the promotion of nuclear energy. The JAIF will continue to work closely with municipalities and local communities in an effort to further address their needs and restore their communities.

With trust in experts having declined, local initiatives need support. The JAIF will help municipalities and local communities autonomously operate their own *kizuna* squares to cultivate a practical radiological culture.

The specific roles that the JAIF would play in this initiative are as follows: (1) to forge partnerships with Mr. Sasaki and other advocates of the initiative; (2) to request support from the national government and municipalities; and (3) to build a network with various experts. The JAIF also intends to provide information to the wider society beyond Fukushima Prefecture so that they can gain a better understanding of the situation in Fukushima. To this end, further cooperation is being requested from members of Atomic Energy Society of Japan.

On a final note, we would like to express our deep gratitude to Mr. Sasaki, now teaching at Koriyama Sixth Junior High School in Koriyama, Fukushima, as well as many related educators, experts, and municipal stakeholders for their valuable insights.

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Towards "Value Judgment" Discussion

−Cases of Nuclear Safety, High-level Radioactive Waste Management and the Role of AESJ−

Tokyo Denki University, **Kohta Juraku**

The Fukushima Nuclear Accident has shaken many of the assumptions that nuclear experts and society as a whole used to take for granted. Fundamental questions are being raised with respect to the manner in which various matters are arranged (or not arranged as the case may be).

Nuclear experts need to leave aside their assumptions and participate in social debates and the decision-making process while fulfilling their accountability based on their own value judgments and the reasoning behind them. Engaging in the discussion of value judgments actively and sincerely in this way is an essential process for nuclear experts to regain society's trust.

I. Introduction

The use of nuclear energy has been debated with increasing frequency throughout society since the Fukushima Daiichi Nuclear Power Plant, which is operated by the Tokyo Electric Power Company, suffered an accident (hereinafter referred to as the "Fukushima Nuclear Accident"). The focus of such debates has obviously been on the questions posed directly by the accident, such as the fate of nuclear power, the development of a roadmap for decontamination and decommissioning, the implementation of measures to ensure and enhance the safety of existing facilities, and the adoption of necessary regulatory reforms.

In addition, the heightened public interest in the use of nuclear energy due to the accident has stimulated further discussions of how highly radioactive waste (high-level waste) should be handled. The accident sparked debates within the Atomic Energy Society of Japan (AESJ) regarding their expected roles and responsibilities, which led to the recent amendment of their articles of association.

With their varied natures and different dimensions, debates such as these have not been listed here just on a whim. They are commonly concerned with the question of value judgments, which defy conclusive decisions based exclusively on technical and specialized discussions.

This commentary considers the deep involvement of value judgments, which defy scientific conclusions in a classic sense even in discussions of science and technologies. To this end, the

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present study focuses on three example issues; namely, nuclear safety, high-level waste disposal, and the expected roles of the AESJ.

II. Value Judgments, and Science and Technologies

Even today, scientific knowledge is commonly believed to offer a unique and optimal solution to the making of judgments and decisions related to science and technologies. This idea seems to be deeply ingrained among experts from the nuclear energy and other fields, politicians, administrators, and citizens throughout society.

However, this assumption cannot be taken for granted in discussions of how society deals with modern science and technologies. This is the basic stance taken in the author's specialist area of science and technology studies.

In almost every discussion of this topic with stakeholders in the nuclear sector, the author cites *Science and Trans-Science* [1)], a paper by A. Weinberg, a former long-serving director of the Oak Ridge National Laboratory in the United States. This groundbreaking paper is frequently cited in discussions of trans-science in science and technology studies. These citations typically advocate the incorporation of dialogues with society, civic participation, and other such elements in decision-making by society with respect to modern science and technologies that defy scientific conclusions without taking into consideration the inalienable question of values (politics) [2)].

There is one more point that we must quickly make before we introduce the concept of trans-science. Importantly, this concept does not argue that scientific knowledge is growing less important or less credible. Nor does it carry any unscientific implications that deny the existence of clear-cut scientific truths. Essentially, Weinberg points out that we cannot make decisions by relying on science alone. This is hardly an agnostic statement like saying "scientific decisions cannot be made" or "nothing can be scientifically explained" to find an easy way out.

With these points in mind, this commentary moves on to address the following core questions. What types of matters cannot be decided solely based on science and in what circumstances? Why are value judgments an inalienable part of decision-making? Why do technical experts have to bear these considerations in mind?

III. Significance of Value Judgments Today

Nonetheless, such discussion would be nothing new among members of the AESJ, so why does the author refer to such a worn-out story here?

Again, this is closely related to the Fukushima Nuclear Accident and the ensuing social debates.

As pointed out earlier, science and values (politics) are inseparable in terms of the humanities and social sciences. This proposition often serves as the basis for encouraging scientists and engineers to consider issues from the perspectives of the humanities and social sciences. However, there is another implication. If we assume that science and values have always been indivisible, any past scientific or expert judgments naturally involved (political) judgments on values as well.

More specifically, it can be reasoned that certain value judgments have inevitably involved various expert judgments in relation to the design, operation, maintenance, and regulation in the nuclear field.

This fact obviously does not disqualify expert judgments. Expert judgments involving value judgments can be effective as long as they maximize the public interest and do not cause significant inconvenience. It takes time and effort for society as a whole to make judgments through exhaustive discussions. Worse still, it may not be possible to form a consensus and the mistakes resulting from mob rule cannot be excluded. The public trusts experts and is willing to delegate many decisions to them as long as they always make universal value judgments based on their expertise.

Before the Fukushima Nuclear Accident, the relationship that the Japanese public had with nuclear experts and engineers could be described in this way.

However the legitimacy of judgments made by experts on the public's behalf was swept away in the wake of the Fukushima Nuclear Accident. The way that the accident unfolded is not the only reason for this. The loss of confidence owes a great deal to the failure of experts to provide adequate explanations of how and why they made their judgments (i.e., lack of accountability). Furthermore, even people who did not specialize in nuclear energy also found the assumptions that they had hitherto taken for granted when making value judgments were shaken to their very foundations or completely replaced (e.g., the unanticipated M9 earthquake that really happened and subsequent tsunami that exceeded their imagination). Suddenly, accumulated expert judgments lost the legitimacy and assumptions that had been endorsed by the public.

In other words, the fundamental question of why a judgment should (or should not) be made in a particular manner was raised with respect to matters that had been held in little doubt and so required no discussion. Examples of these matters include envisaged earthquakes and tsunamis, plant designs, and relevant standards and plans. Assumptions such as these that served as the basis for validating a certain condition all came under scrutiny.

This is the moment when value judgments became necessary and important again. Experts rely on their scientific knowledge to make judgments about matters such as whether a certain assumption is acceptable, why Design A should be adopted instead of Design B for a specific part, and why the deployment of only two rather than three devices is sufficient. These judgments and choices always involve value judgments, as typified by comparisons of the costs and benefits. In every respect, it became necessary to restructure and explain the relevant logic to gain social approval.

1. Nuclear Safety

(1) Aporia that new nuclear safety regulations face

The foremost example of the relevant challenges involved is nuclear safety.

Reviews were commenced based on new standards for regulating the safety of existing nuclear power plants, but these reviews still cannot clearly answer the long-established question of how safe is safe enough.

Some readers may point out that the Nuclear Regulation Authority (NRA) finally established safety goals as a definitive answer to this question. The author does not deny the benefits and importance of safety goals.

The issue here, though, is who answers that question. Strangely, the NRA set these safety goals rather suddenly without any trace of the expert discussions that would usually precede decisions as important as this. It is not even clear whether the safety goals were officially established. In fact, a newspaper article even explained that commissioners could not settle their differences during the deliberation process [3).

If that is the case, the latest safety goals can hardly be considered a substantive answer that has been reached by the whole of society after deep deliberation.

Under these circumstances, no matter how much more rigorous the standards that we establish are and how strictly they are applied, people will continue to ask why that is enough and whether nothing more needs to be done. Regulatory authorities and utility companies must endlessly implement additional safety measures, but there is no guarantee that this will earn the public's trust and confidence. Given this, it seems that the aporia, i.e., too difficult question that cannot be resolved, is emerging.

(2) Inevitable discussions of value judgments and the role of politics

The only way to resolve this aporia is to discuss value judgments with respect to nuclear safety. To begin with, the whole of society must discuss how we determine how safe is safe enough and how we draw specific conclusions. After that, the future of nuclear safety must be discussed with due reference to these conclusions. There is no other way forward.

Starting this task and reaching a consensus will obviously not be easy.

Nonetheless, the way in which discussions should take place and under whose initiative is more or less clear. The essence of politics is to pursue conclusions about certain values through discussion.

It should be noted, however, that politics is being discussed conceptually in this context, with no meaningful reference to particular parties, politicians, ministries, agencies, or other political actors in Japan.

Unfortunately, politics in Japan today seems to have lost touch with its original purpose. Understandably, some readers will assume rather pessimistically or skeptically that the task is impossible or feel that leaving judgments to politics is ill advised.

However, this aporia cannot be overcome by simply resigning ourselves to pessimism over the current state of affairs. For instance, the controversy over the resumption of nuclear power is an extension of the issue of safety standards that require value judgments to be made concerning safety. The government leaders have left all of the substantial decision-making to the NRA supposedly out of respect for their judgments.

Although detailed discussions will have to be left for another occasion due to space limitations, we should note that a safety review by the NRA is classified as a risk assessment, which is distinct from (and not necessarily directly connected to) risk management and comprehensive risk judgments according to conventional understanding. As has already been explained, it is impossible to determine whether a risk assessment result indicates safety or not safety unless an answer is provided to the question of how safe is safe enough.

Decision-making about the procedures, methods, and criteria involved in judging whether something is safe or not safe clearly belongs to the domain of politics.

Without a political process such as this, any deeper discussions about safety will end up being mired in futile controversies, no matter how scientifically and professionally they may be conducted. The prevailing critical public view on nuclear safety will make it even more difficult for public trust to be gained by insisting in discussions that the safety regulations are adequate and that nuclear energy is not dangerous (e.g., whether an active fault runs immediately beneath a reactor core or the premises of a nuclear power plant).

Nuclear experts are not expected to venture too deeply into technical discussions on these issues. Instead, to facilitate the original function of politics, they are expected to present the results of safety assessment and technical options aimed at enhancing safety so that society can make value judgments.

2. Disposal of High-Level Waste

(1) The gap between needs and safety

The Fukushima Nuclear Accident drew the attention of the public to not only the safety of existing nuclear power plants and associated facilities, but also the disposal of high-level waste (hereinafter referred to as “HLW disposal”). This topic is being actively debated throughout society, and feedback from the Science Council of Japan has demanded a radical overhaul of the current approach[4].

A study conducted by the Nuclear Waste Management Organization of Japan (NUMO) clearly indicates growing interest in HLW disposal and greater perceived needs even though no major changes have been observed with respect to awareness of HLW disposal before and after the nuclear accident[5]. However, this is not necessarily a positive trend. In fact, it would be more reasonable to interpret this change in a negative sense (e.g., concerns over safety) considering the media coverage and the flood of information on radioactive waste (which is, of course, mainly waste from decontamination work and other waste produced in the response to the Fukushima Nuclear Accident).

In fact, the same NUMO study noted a significant year-on-year drop in the perceived level of safety in relation to HLW disposal in the first survey conducted in February 2012 after the accident. Even in the latest survey, which was conducted in February 2013, confidence has not recovered to the same level as that of February 2011. A similar trend can be observed with respect to the share of opinions in favor of HLW disposal. The heightened perceived needs have not been matched by any increased endorsement of safety and disposal.

As you may know, the HLW disposal project has not achieved any notable progress since the enactment of the Designated Radioactive Waste Final Disposal Act (Final Disposal Act) in 2000, the establishment of NUMO, and the call for proposals for candidate repositories.

Countless efforts have been made to address this problem based on the assumption that the fault lies with an inadequate understanding of safety among the public.

(2) HLW disposal as a social undertaking and value judgments

Public interest in the safety of HLW disposal is unmistakably very high.

It seems, however, that those people who voice concerns over the safety of HLW disposal seem to be worried about more than just the objective results of safety assessments.

HLW disposal must envisage a significantly longer time frame compared to many earlier human undertakings. A major issue, then, is how we should deal with the uncertainties of the future. The idea of deep geological disposal was devised and developed to offer a solution to this issue, but most people will be unfamiliar with its basic concept.

In general, one possible approach for addressing a high level of uncertainty is to anticipate various scenarios, prepare necessary measures in advance, and then manage the risks while monitoring and responding to the situation as appropriate. In contrast, deep geological disposal seeks to manage these risks to the extent necessary without active human involvement by making the most of the natural containment capacity of the environment deep underground. The validity of such an approach is hardly intuitive for non-experts.

There are obviously good reasons for experts in deep geological disposal to regard this approach as the best option. For instance, history teaches us that society undergoes too many changes over the time frame envisaged for repositories. There is no guarantee that society in the future will be able, or willing, to maintain the level of management that is expected by today’s society.

On reflection, such reasoning also seems to involve value judgments. It must be stressed that this fact in no way invalidates the reasoning. Instead, attention should be paid to the fact that the choice and conception of deep geological disposal were not driven solely by technological advancements in a narrow sense. This idea has been validated as a social project through various discussions and decisions from political, economic, legal, ethical, and other perspectives. During these processes, value judgments have been made repeatedly to determine which option is desirable.

In other words, deep geological disposal is a social undertaking with a specifically proposed plan that extends far beyond the narrow confines of technologies. This principle will remain the same even if other technologies are discussed, adopted, or combined for the HLW disposal.

Experts in deep geological disposal most likely share this sense of a social undertaking as they continue to engage in sincere discussions to make value judgments. If we examine past reports prepared based on the input of experts from various countries, such as those published by the US National Academy of Science and the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development, we can clearly see how these discussions have been conducted and knowledge has been accumulated[6, 7)].

(3) Discussions of value judgments as a social experience

So, why has deep geological disposal not gained social confidence and support as an answer based on years of wisdom? The main reason is that society has never experienced value judgments by getting involved in these discussions.

The foremost shortcoming that can be identified in relation to the abovementioned sincere discussions is the fact that discussions and decisions concerning values have been made only among experts.

To be fair, these experts did not actively try to exclude other actors. However, there must surely be room for improvement in terms of making adequate efforts to engage other actors in a series of dialogues.

In the mid-1990s, for example, prior to the enactment of the Final Disposal Act, the Japan Atomic Energy Commission established a commission for the disposal of high-level waste with the aim of compiling a report based on discussions among experts from different fields and with a diverse range of views. Later, the law was enacted within roughly two and a half months of the bill being submitted. In fact, the interpellation session conducted in each house of the Diet took practically a single day to discuss the bill. It is also known that the bill was passed and enacted by an overwhelming majority in both houses after just nine days of their respective committee's deliberations[8)].

It is certainly possible to explain this by assuming that this robust bill left no room for any objections or questions. However, such scanty deliberation is not desirable given the fact that HLW disposal entails a crucial value judgment for society. Such rough-and-ready decision-making leaves little room for society to share related experiences in jointly discussing HLW disposal until a convincing value judgment can be made. As a result, even this legally accepted disposal project cannot easily gain political and social legitimacy.

Today, in 2013, actors with conflicting views seem to be arguing over what the specific envisaged risks for deep geological disposal are and how countermeasures should be taken (e.g., the seismic impact on the safety of repositories). Their arguments do not necessarily bear in mind the importance of the abovementioned value judgments.

Any discussion of safety is likely to end up in aporia no matter how much the results of risk assessments are expounded unless values are discussed beforehand to provide indicators for risk management. This is in line with the safety regulations for nuclear power plants, as discussed in the previous section.

This folly must be avoided by enabling all of society to re-experience the value judgments and derive their own answers. To this end, experts in deep geological disposal and other stakeholders should present multiple options after clarifying their reasoning and the answers that they reached with respect to various questions involving value judgments, such as reasons to go ahead with deep geological repositories at this point and how the chosen approach can ensure their safety. An initiative must be adopted to facilitate society-wide discussions and cooperation in order to go beyond the simple communication of judgments made only among experts.

The issues to be addressed through societal discussions and cooperation have also been compiled by a special committee under the AESJ for an interdisciplinary evaluation of the deep geological disposal of radioactive waste. The findings of this committee—to which the author also belongs—are expected to be presented in the final report this autumn.

3. Expected Roles of the AESJ

In closing, it should be noted that the AESJ is also expected to engage in the discussion of value judgments.

The Fukushima Nuclear Accident prompted various discussions within the AESJ on this topic, which also led to the amendment of their articles of association. The Investigation Committee on the Nuclear Accident at the Fukushima Daiichi Nuclear Power Plant has also submitted a report on the desired roles of the AESJ and necessary remedial measures. As of the time of writing, a call for public comments on this report is underway.

Nonetheless, attention must be paid to the possibility of vast differences in the views held by AESJ members regarding the nature of learned societies as well as where their fundamental values lie.

Japan embraced engineering after the Meiji Restoration in a bid to build up its wealth and military power by boosting new industries. This was when engineers in other countries began to organize themselves. For this historical reason, groups of engineers have been regarded as learned societies in Japan[9)].

In countries other than Japan, groups of engineers tend to carry strong echoes of their origins as professional associations during the movement to advance engineers. They seek to enhance the status of engineers and preserve their dignity through social contributions and professional behavior. They often clearly indicate that they are made up of engineers (e.g., the American Society of Mechanical Engineers). In this context, the AESJ could also reflect on how future activities should be conducted and how its members should be involved.

In contrast, engineering societies in Japan have developed as learned societies with a distinctly academic nature since their establishment. In line with this tradition, those who value the academic freedom and autonomy of researchers may voice a sense of discomfort with the idea that the AESJ governs its members, makes collective statements, and takes public actions.

In this context, value judgments must also be discussed with due consideration given to the multiple stances and views that exist with respect to the fundamental question of what a learned society is. Otherwise, members who regard themselves as part of a group of professionals and their more academically oriented peers may end up involved in futile counter-accusations. Unable to understand the intention and significance of proposals from the other camp, they may also end up being preoccupied with differences instead of working to deepen discussions concerning the future roles of the AESJ. In fact, active participation in discussions concerning value judgments is essential not only between experts and society as a whole, but also among experts.

IV. Conclusions

The Fukushima Nuclear Accident has shaken many of the assumptions that nuclear experts and society as a whole used to take for granted. Fundamental questions are being raised with respect to the manner in which all matters are arranged (or not arranged as the case may be).

Nuclear experts need to leave aside their assumptions and participate in social debates and the decision-making process while fulfilling their accountability based on their own value judgments and the reasoning behind them. Engaging in the discussion of value judgments actively and sincerely in this way is an essential process for nuclear experts to regain society's trust.

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A Fresh Start of Nuclear Safety Regulation and International Perspective

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Reluctance is no justification for a failure to humbly acknowledge and explain that the Fukushima Nuclear Accident was a man-made disaster. Inward-looking attitudes should be cast aside and every possible effort must be made to rebuild a safety culture. Soul-searching into the Fukushima Accident must not end up being superficial. The operational system and human resource infrastructure urgently need to be reinforced by the Nuclear Regulation Authority and its Secretariat to deal with the country's growing international obligations to implement the necessary security, safeguard, and safety (3S) measures comprehensively.

I. Introduction

Almost three years have passed since the accident at the Fukushima Daiichi Nuclear Power Plant, operated by the Tokyo Electric Power Company (TEPCO) (hereinafter referred to as the "Fukushima Accident"). Even after the cold shutdown of its reactors announced in December 2011, thorny problems such as the treatment of contaminated water, the decommissioning process, and other medium- to long-term challenges loom large across the country.

Meanwhile, newly established in September 2012, the Nuclear Regulation Authority (NRA) took the first step toward fundamental reform of the public administration of nuclear safety amid many challenges. In the mission statement finalized shortly after its establishment, the NRA upheld as one of its five principles: To remain a transparent and open organization that respects the diverse opinions voiced in Japan and overseas while avoiding isolation and self-righteousness. This principle is the result of much soul-searching over the past mistakes including a cavalier attitude toward international standards and collaboration.

On this occasion, the NRA assumed a centralized role and responsibility for so-called "3S" measures: ensuring nuclear Security against terrorism and other hazards; implementing Safeguard measures against nuclear proliferation; and promoting nuclear Safety. The NRA's scope of responsibility was thus expanded to handle a greater number of international assignments of a wider variety, adding new challenges for the NRA.

This commentary attempts to describe the current state of the NRA with a focus on its

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international aspects and assignments. The opinions and views presented herein are those of the author and not necessary of the NRA.

II. Active International Attention and Interests

Many countries remain keenly interested in the Fukushima Accident because it is the major nuclear accident that occurred since the Chernobyl Accident of 1986. Their interests cover a wide range of issues, including the following: the causes of the accident; how the safety of spent fuel pools and damaged reactors is being ensured; lessons that should be learned; the principles and substance of new regulatory standards for nuclear safety; whether, and when, nuclear power plants will resume operation in Japan with the end of the current shutdown; how the contaminated water that continues to build up would be treated; how the decommissioning and decontamination work should be handled; how nuclear regulatory institutions are being reformed; trends in public opinion over nuclear energy issues; and the future of Japan's nuclear policy in relation to the export of power plants and nuclear fuel cycle.

Such a wide-ranging international attention has been shown in the recent numerous international conferences and workshops focused on the Fukushima Accident, in some of which the author had the opportunity to participate. They include lectures and panel discussions held at a Science and Technology in Society (STS) forum organized by an NPO (October 2012, Kyoto); the trilateral senior regulators meeting from South Korea, China, and Japan (November 2012, Seoul); the ministerial meeting on nuclear safety held in Fukushima and organized by the International Atomic Energy Agency (December 2012, Fukushima); IAEA's meeting of nuclear safety regulators (April 2013, Ottawa); IAEA's expert meeting (May 2013, Vienna); and a meeting of safety regulators from Europe (ENSREG, June 2013, Brussels). In addition, Japanese experts from the NRA, JNES, JAEA, TEPCO, and academic societies have also participated in the relevant meetings in the United States and France, as well as those hosted by the NEA of the OECD.

III. Sharing Information with the Rest of the World

Close attention is naturally directed at the remarks made by participants from Japan, the country that experienced the recent nuclear accident, regarding the specific information they provide and how they present it. There would be little problem if those participants share their personal opinions and observations freely in their individual capacity. However, when they speak representing the government or any authoritative organization and explain or respond to questions with some background authority, then the matter would become not so simple or easy.

In the wake of the Fukushima Accident and up to now, a number of accident reports have been issued in Japan, by the Diet, the national government, TEPCO, the private sector group, the Atomic Energy Society of Japan, respectively. On which of them to relay for presentation? In my case, I have relied mainly on the facts and findings presented in the Diet investigation report published by the Fukushima Nuclear Accident Independent Investigation Commission (NAIIC). This investigation commission was organized by the National Diet and I had the privilege of serving as its member. Now generally known as the "Kurokawa Report," picking the name of the NAIIC's Chairperson, this voluminous report has been swiftly translated into

English in its entirety and shared with the rest of the world. As a result, this report seems to have been widely read by interested experts overseas and well received, in part due to its detailed analysis and evaluations.

Often in discussions at these meetings or during coffee breaks, a wide range of relevant questions are asked by the participants, including the following:

(a) Could the accident have been prevented, if so, how?;

(b) Why did Japan, aware of its high risks and vulnerability by exposure to earthquakes, end up building so many nuclear power plants?;

(c) How were the risks calculated when constructing multiple reactors at one site?;

(d) What impacts did the earthquake and tsunami have each as the cause of the accident?;

(e) What made the difference between the escalation into a severe accident at the Fukushima Daiichi Nuclear Power Plant on the one hand, and the avoidance of such an accident at the three power stations in its vicinity, namely at Onagawa, Fukushima Daini, and Tokai Daini, on the other hand?;

(f) How will the regulatory system and crisis management be improved in a post-Fukushima Japan?; and

(g) Did the evacuation of residents work out well? What were the bottlenecks, if any?

Such questions and observations coming from the participants no doubt reflect their own serious concerns with respect to their own countries, as well as the results of their in-depth studies of the issues.

At the same time, some comments were also heard to the effect that while fully sympathizing with the Japanese about the extent of the shock from the Fukushima Accident, whether the new regulatory standards that are being developed might be handled either too hastily or unrealistically severely.

It is frankly admitted that for someone like this author, with a liberal arts background, the task to provide an adequate account of the complex nuclear accident, in its scientific and technical aspects for the benefit of overseas experts and the media, is next to impossible. The task may become slightly less complicated when it comes to explaining the human, structural, or organizational aspects of the issues, and the indirect causes and underlying factors of the accident, although that is still no easy thing to do.

That said, any account of the causes and underlying factors of the Fukushima Accident cannot be complete or credible without touching upon the central issue, namely, the weaknesses in the prevailing nuclear safety culture or the so-called “safety mythology” in Japan. But, frankly speaking, to do this in front of foreign nuclear experts could entail certain hesitation or uneasiness because it comes down to revealing what amounts to “false assumptions” and “national blunders” that Japan had made before the accident. They include perceptions, for example, that “nuclear power plants are safe and carry no risks,” “extended power loss need not to be worried because of the country’s well-established and reliable power supply infrastructure,” “severe accidents will not happen, and therefore appropriate countermeasures can be left to the power utilities,” etc.

However, the fact is that the Fukushima Accident was a rare major nuclear accident that caused anxieties, not only in Japan but also in the neighboring countries and beyond. And the concerns created will continue to arrest the international attention in the future. This is the reason why convincing accounts and explanations must be provided, and repeated, both in direct communications from Japan and in the remarks made at international conferences and exchanges. Japan should humbly share the lessons learned after much soul-searching with the international community, and set a positive example by implementing those lessons to reform itself. This is no doubt what the international community expects of Japan. Such a realization should prevail over any perceived sense of hesitation or shame. A sincere attitude and commitment in correcting what went wrong will be the surest way for Japan to recover from its damage and regain international trust for the country.

Having said that, I must frankly admit that there is no pleasure or satisfaction felt even when someone from the audience in international meetings comes forward and compliments by saying, “Your frank and straightforward briefings today were extremely informative and helpful.” Far from any pleasure, I found myself always left with some uneasy or mixed feelings. Thankfully, perhaps out of sympathy or courtesy for the country that suffered the terrible disaster, it seemed participants tended to avoid asking the sort of questions that are too embarrassing or annoying to the Japanese. In this context, on one, two or three occasions I recall one particular comment by a participant, not in the meeting room but during casual conversations outside the meeting room, who said, to the effect, “I heard you express remorse over Japan’s lax nuclear safety regulations and weak safety culture. Even so, I find it very disappointing that, of all countries, a technological powerhouse like Japan made such mistakes, particularly after experiencing the tragedies of Hiroshima and Nagasaki.” As a citizen who comes from Hiroshima myself, I had no word to respond to it.

IV. Human Factors

The Kurokawa Report clearly concludes that the Fukushima Accident must be understood as a “man-made” disaster. Other reports on the accident share this common assessment regardless of the wording. Even TEPCO, as the main party responsible for the accident, backed away from its initial excuse that the accident was caused by an “unexpected natural disaster” and admitted that there were man-made factors. The TEPCO representative also clearly acknowledged this fact in one of the IAEA’s expert meetings in May 2013.

Recognizing the Fukushima Accident as a man-made disaster would mean the need to pay the closest of attention to various human factors; in other words, the level and quality of the prevailing nuclear safety culture with respect to the human, structural, and organizational aspects, as the indirect causes and underlying factors. Triggered directly by a huge natural disaster—giant earthquake and tsunami—the Fukushima Accident was complexly compounded by human factors (mostly omissions). This means that it should be understood as an unlucky major “complex disaster” and aspects of human factors should not be omitted or minimized alongside the discussions of natural factors.

V. Three Mile Island and Chernobyl

Human factors were also included as the main causes of the Three Mile Island (TMI) Accident that occurred in the United States (1979) and the Chernobyl Accident (1986). The President’s Commission on the TMI, chaired by John G. Kemeny, made specific recommendations regarding necessary improvements, based on a detailed analysis of the accident’s causes by identifying human, structural, and organizational problems and weaknesses in the safety regulation system that was employed in the United States at that time. This analysis went beyond findings of the operational mistakes made by the operators of the reactor. Eventually, after some twists and turns, the United States gradually implemented one recommendation after another to build up a robust regulatory system, including the reinforcement of the Nuclear

Regulatory Commission (NRC). A comparison of the Kemeny Report and the Kurokawa Report, despite the differences in the scale and circumstances of each case, reveals many striking commonalities with respect to the human factors.

Aside from these commonalities, Japan probably has much to learn from the way the United States summed up its experiences from the TMI Accident, planned specific steps for its regulatory reform, and enhanced nuclear safety through a range of painstaking and steady reforms and improvements made by both the public and private sectors. For instance, the Institute of Nuclear Power Operations (INPO) was established as a mutual monitoring system by power utilities at their own initiative after much soul-searching over the TMI Accident. Together with the NRC, the INPO plays a unique role as an inseparable part of the system designed to ensure nuclear safety. It would be encouraging if such a system could take shape in Japan also. Japanese citizens may well be watching to see if not only TEPCO but Japan's power industry as a whole will adopt any decisive initiatives aimed at enhancing its self-corrective functions and safety culture, rather than just dismissing the Fukushima Accident as a one-off experience of a single company.

Restoration of a sound nuclear safety culture by the regulatory bodies and the power industry is an essential minimum step in regaining the public's trust. However, there are also many other genuinely important challenges that will need to be tackled in the future. They include, but are not limited to, redefining the roles of the national government, the relationship between the national government and host municipalities, and the optimal crisis management system. A preoccupation with the immediate tasks required to deal with the consequences of the Fukushima Accident cannot justify a rushed attempt at superficial soul-searching and reforms. The author expects that constructive discussions will initiate among the legislative and executive branches, the power industry, and civil society to produce some tangible outcomes. Clearly, measures adopted in one country may not fit the different conditions prevailing in another country. Nonetheless, good practices and worthwhile lessons from overseas should be considered for adoption in our country without hesitation.

VI. How Lessons are Learned Outside Japan

Let us see how some countries and international organizations are trying to learn lessons from the Fukushima Accident.

1. IAEA

As the lead international agency for nuclear safety and regulations, the IAEA embarked on the drafting of a summary report on the Fukushima Accident. Experts are working under the leadership of Director General Yukiya Amano to complete this report by the end of 2014. Japan is also taking part in this project. The Fukushima Accident, along with the country report submitted to IAEA by Japan, is likely to draw particular attention at the next triennial Review Meeting of the Contracting Parties to the Convention on Nuclear Safety, to be hosted by the IAEA in March 2014.

2. Europe

In Europe, under the European Union and its framework the European Nuclear Safety

Regulators Group (ENSREG), 14 member countries that have nuclear power plants began conducting their respective safety checks (stress tests), by assuming the occurrence of accidents triggered by natural phenomena. Those tests apparently did not disclose immediately any general issues that may directly impair the safety operation of the existing nuclear facilities. Nonetheless, they seem to have identified some points for improvement with respect to reinforcing measures against natural disasters. The results of the stress tests conducted in the respective countries have been subject to EU-wide peer reviews. These findings have been reported at meetings of the ENSREG, and each country is trying to reinforce its safety measures. For this reason, they maintain a keen interest in the lessons learned from the Fukushima Accident.

With regard to human factors, France—leading nuclear power in the EU—has established a working group on human, social, and organizational factors (HSOF) under France's regulatory body, the Autorité de Sûreté Nucléaire (ASN). They seem to be trying in their own way to apply the lessons learned from the accidents experienced in Japan to enhance nuclear safety in France and the rest of Europe.

3. United States

In the United States, the National Academy of Sciences has begun to extract reference cases related to the Fukushima Accident as requested by Congress. A report by the INPO and various other reports are being drafted. The NRC has also launched the Japan Taskforce with about 20 assigned personnel to extract reference cases and draw lessons from the accident.

VII. How Lessons Have Been Learned by Japan

The swift and proactive attitude to learn from overseas accidents shown by the two leading nuclear powers—the United States and France—and other European countries demonstrate their strong sense of commitment to constantly enhancing their nuclear safety culture. Even before the Fukushima Accident, these countries actively sought to enhance their nuclear safety by taking heed of the lessons learned from the TMI and Chernobyl Accidents. By 2009, EU member countries and the United States had reportedly aligned their safety regulations with IAEA standards.

So, compared to them, how did Japan fare as the world's third largest nuclear power producer? Reports by the NAIIC and by other bodies have pointed out that, before the Fukushima Accident, Japan's regulatory authority tended to be inward-looking in its approach and did not make much effort to incorporate international standards and good practices from other countries. As a result, the country remained out of touch with the international trends and lagged behind others in terms of efforts to enhance nuclear safety. According to a well-informed commentator, Japan "found itself in an abnormal situation, a country that remained out of the loop."

A symbolical example of this is the way in which Japan chose to deal with a mission carried out by the Integrated Regulatory Review Service (IRRS) of the IAEA to conduct a peer review. Japan did host a mission as required in 2007, but it failed in taking the necessary action to follow-up on the mission's findings. Indeed, the Fukushima Accident occurred in March 2011, which exceeded the three-year timeline for hosting a follow-up mission as required, for improving the matters identified previously.

In this regard, the NAIIC Report summarized the problem as follows: “The nuclear sector in Japan is strongly disinclined to disturb the status quo, clinging stubbornly to the existing nuclear safety system. The regulatory authorities and power utilities do not discuss what needs to be done to improve safety. Instead, they tend to focus on ways of convincing the public, the host communities, and the international community that existing measures are adequate to ensure nuclear safety.”

Indicative of the prevailing attitude at that time, such an attitude epitomizes the degradation of Japan’s safety culture. One must admit with deep remorse that the entire nation had to pay dearly for this failure in Fukushima. For this, all the stakeholders carry a grave responsibility. Clearly, it is vital for us to take this lesson to heart, put the previous attitude and mentality behind, and open up Japan’s regulatory framework to the outside world. The NRA bears an important responsibility in leading these efforts.

VIII. International Engagement by the NRA

I would now turn to deal briefly with how the NRA has begun its international engagement, in particular on the 3S measures.

1. Cooperation with the IAEA—Early Hosting of IRRS and IPPAS Missions

Japan and the IAEA are about to start the hosting of peer review missions. The first one will be a mission by the IRRS. Japan needs to make a fresh start given the afore-mentioned mistakes made in the past. The IAEA also wishes to have this mission take place at an early stage. NRA’s Chairperson Shunichi Tanaka and IAEA’s Director General Yukiya Amano have confirmed their agreement in principle for an early IRRS mission to Japan. The appropriate timing is to be decided so as to allow proper preparations and to ensure substantial outcomes by this mission. Once the new set of regulatory framework and standards are in place for nuclear safety, Japan must engage seriously with international peer reviews and apply their findings earnestly to enhance its nuclear safety.

The second peer review mission, which Japan should host at an early stage, is the International Physical Protection Advisory Service (IPPAS), also operated by the IAEA. IPPAS provides advice and assistance for improving and reinforcing frameworks for preventing nuclear terrorism (physical protection). So far, 30 countries, including the United States, France, and South Korea, have hosted these missions, yet Japan has failed to keep up with others in hosting it. Japan has announced its plan to host a workshop this year with the IAEA as part of prior preparations (as stated by the State Minister for Foreign Affairs at the ministerial meeting on nuclear security held this July, 2013), and preparatory work is underway.

2. Reinforcement of Nuclear Security Measures

The Fukushima Accident revealed how a station blackout at a nuclear power plant can trigger grave emergencies and where a plant’s vulnerabilities lie. One lesson derived from the experience of Fukushima is the need for nuclear power state to take effective measures against acts of terrorism targeting nuclear facilities and nuclear material transportation. With this in mind, it is necessary to make every effort to implement nuclear security measures as well as nuclear safety. Nuclear terrorism should never be tolerated anywhere in the world, so heads of states have demonstrated their serous concerns about nuclear security at the 2010 Summit held in Washington, D.C. The next summit is to be held in the Hague, the Netherlands, in 2014, to be followed by another one in Washington, D.C. in 2016.

In Japan, nuclear security measures used to be implemented by various government bodies under the overall coordination of the Special Committee on Physical Protection under the auspices of Atomic Energy Commission. This coordination role has now been transferred to the NRA, and under its leadership the security measures must be reinforced based on the experiences gained to date. To enhance its nuclear security, Japan has incorporated in its own regulations, a set of international standards such as those contained in the relevant international treaties and IAEA recommendations. In terms of international treaties, following the ratification of the Convention on the Physical Protection of Nuclear Material in 1988, an early ratification of the amended Convention (2005) is envisaged.

Nonetheless, on nuclear security there are still matters of concern that must be addressed. For instance, the Nuclear Threat Initiative, an American NGO, ranked Japan 23rd out of 32 countries in terms of its overall international rating (as of January 2012). This poor rating seems to be associated with the large amount of nuclear materials stocked in the country and the absence of an independent regulatory body (at the time of the rating). Furthermore, Japan ranked near the bottom at 30th with respect to personnel-related measures for ensuring security. What is behind such a poor rating?

This rating is related to the issue of personnel-vetting as an important pillar in the prevention of internal threats. In line with an IAEA recommendation, personnel vetting has been adopted by all the major nuclear powers, except Japan. Our country has not dealt with this issue yet, which involves the protection of personal privacy, despite the widely acknowledged need for a storage and inquiry system for personal information in order to prevent internal threats by verifying the credibility of personnel and workers at a nuclear facility.

For this reason, the NRA has established a “Study Group on Nuclear Security” to introduce a personnel-vetting system and pursue tangible measures aimed at addressing other challenges (e.g. nuclear security measures during transportation as well as for radioactive materials and relevant facilities). The Study Group is examining specific measures and activities to implement them with the aid of external experts and the relevant ministries and agencies. The early hosting of the afore-mentioned IPPAS mission is also a part of these efforts.

3. Safeguards Against Nuclear Proliferation

Previously, safeguards-related work had been handled between the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the Ministry of Foreign Affairs (MOFA). In April 2013, this work was delegated to the NRA following a transfer of personnel from MEXT and of the necessary budget. From now on, the work will be handled by the NRA and MOFA. Japan has long been the second-largest contributor to the IAEA budget. Furthermore, the country has been by far the top target of IAEA safeguard measures, with about 30% of its human and financial resources allocated for Japan.

With this background, Japan and the IAEA have built up a relationship based on trust and close cooperation as an asset. As it embarks on a fresh start, the NRA should build on this asset to reinforce its cooperation with the IAEA on nuclear non-proliferation and do its best to ensure that its safeguard measures do not give rise to any mistrust or doubts. Going even further, it should intensify its international cooperation on nuclear non-proliferation in Asia and beyond, while taking full advantage of Japan’s experience and technologies in nuclear safeguards.

4. Bilateral Relations with the US, France, the UK, Russia, and Other Countries

Japan has maintained a certain level of bilateral relations focused on information sharing with other major nuclear powers. As the NRA began its fresh start, it signed memoranda of understanding with several countries in recognition of their needs to strengthen such cooperative ties.

To begin with, with the US and France, new arrangements were agreed to on the holding of regular meetings between the regulatory authorities of the respective countries (i.e., the US-Japan Steering Committee and the France-Japan Bilateral Committee, respectively). These meetings will be held both at the Commissioner level and the expert level to strengthen cooperation and partnership. A similar agreement with the UK is also under consideration. Russia has expressed a desire to strengthen its previously tenuous ties with Japan in the aftermath of the Fukushima Accident and a memorandum of understanding is expected in the near future.

These agreements are expected to intensify activities aimed at promoting information sharing, mutual visits of experts, and personnel exchanges as well as hosting seminars and workshops, and looking for opportunities for joint projects.

Under the US-Japan cooperation agreement for the peaceful use of nuclear energy, the NRA is looking to establish a new arrangement with the US Department of Energy to cooperate in R&D within their assigned jurisdictions. The establishment of new partnerships with the Nordic countries is also being considered.

5. International Advisors

After the Fukushima Accident, three internationally renowned experts have been commissioned as NRA’s foreign advisors to seek advice from a broader international perspective based on their rich experience: Dr. Richard Meserve, the former chairman of the NRC in the United States; Dr. Mike Weightman, the former chairman of the Office for Nuclear Regulation (ONR) in the United Kingdom; and Dr. Andre-Claude Lacoste, the former chairman of the ASN in France.

IX. Conclusions

What should Japan learn from the Fukushima Accident and how should it enhance its nuclear safety culture? Our challenges have just begun. It is imperative to overcome our hitherto inward-looking attitudes. There is no end to cultivating and improving a genuine safety culture. Aside from the continuous efforts required of all the stakeholders, it is essential that we change and reform the mindsets of power utilities, regulatory authorities, and citizens. The establishment of the NRA is just the starting point for this endeavor, not the finishing point. International efforts have been initiated as outlined above, but much has yet to be fleshed out and implemented.

As mentioned at the beginning, the Fukushima Accident led to a marked increase in the complexity and amount of work in international areas of assignments for the NRA and its Secretariat. As well, as a nation that caused a major nuclear accident, Japan must live up to higher expectations to share information with the international community properly. Japan obviously needs to bolster its operational system and human resource infrastructure to be able to provide the level of international engagement necessary to meet these needs and expectations.

This need is clearly acknowledged in the legislative process, reflected in the provisions of the Act for Establishment of the Nuclear Regulation Authority (June 2012). More specifically, Article 6 of the Act's supplementary provisions lists measures for the personnel of the NRA Secretariat, for those engaged in international assignments and other assignments, that ought to be swiftly carried out by the government. Examples of the measures include: ensuring adequate level of salaries and compensation; improvement of working conditions for the staff; ample sourcing of new recruits; proactive recruitment of talented individuals from universities, research institutes, and private companies; providing opportunities for staff training and learning through overseas studies, personnel exchanges, assignment to relevant international organizations, foreign regulatory agencies, and Japan's embassies; establishment of training facilities and building up of training capacity; and adequate budgetary appropriations for the NRA, etc. It should be stressed that these measures are necessary to recruit and retain talented personnel who are internationally minded and highly motivated. The Act also stipulates the integration of the Japan Nuclear Energy Safety Organization (JNES) into the NRA as a move intended to strengthen the expertise of regulatory bodies.

The Act may be said to be quite unique in the sense that in establishing a new organization, it sets forth in such detailed, clear targets and disciplinary directions related to the organization and its human resources. This is rather uncommon in Japan and is clearly a reflection of the legislature's strong expectations and hope for the new regulatory bodies that have been created after much soul-searching over the Fukushima Accident.

The real challenge, of course, lies in the steady and faithful implementation of these measures. Some are already being carried out, but efforts have yet to be exerted in earnest. Even though it may not be possible to catch up overnight with the level of the NRC in the US or the ASN in France, something more than just "business as usual" is required. Given the character of bureaucratic structure and culture in the Japanese government, focused political backup may be required to help push the cart along as charted in the Act. At the start, we all expect that those in the regulatory authorities and concerned government officials will exert their best efforts toward achieving the worthy objective.

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Perceptions Research of PR Staff Members with Respect to Communication with the French Mass Media following the Fukushima Daiichi Nuclear Accident

–Interviews Conducted with AREVA, EDF, CEA, and IRSN–

Japan Atomic Energy Agency, **Tatsuro Tsuchida**

The Fukushima Daiichi Nuclear Accident received prominent media coverage not only in Japan, but also in France as the world's leading nuclear power producer. What types of public relations (PR) systems did the French nuclear related organizations adopt to share information with media outlets? What kinds of attitudes did PR staff adopt when they communicated with journalists? Interviews were conducted with PR staff to perform a qualitative assessment of how French nuclear related organizations shared information with the media. With nuclear risks gaining global reach, France successfully enhanced the value of news about the nuclear accident in another country. This commentary examines this experience by focusing on the attitudes of the PR staff.

I. Background and Purpose

1. French Response to the Fukushima Nuclear Accident

The accident that occurred at the Fukushima Daiichi Nuclear Power Plant (hereinafter referred to as the "Fukushima Nuclear Accident") led to the shutdown of all 54 reactors at Japan's nuclear power plants for the first time in the 42 years. This nationwide shutdown began when a regular inspection was conducted at Unit 3 of the Tomari Nuclear Power Station on May 5, 2012. The Fukushima Nuclear Accident also prompted Germany to phase out its use of nuclear power. In contrast, the Sarkozy administration maintained a pro-nuclear stance in France. The country's 58 nuclear reactors continued to be employed as the primary source of power even after Hollande took over the presidency.

Nuclear power accounts for over 70% of the electricity supply in France. The world's second-largest nuclear power producer after the United States, France leads the way in terms of international cooperation in the development of nuclear power technologies. Examples of

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this include the introduction of the European Pressure Reactor, as well as research and development into next-generation nuclear power systems and nuclear fusion reactors. It is easy to imagine that the Fukushima Nuclear Accident received prominent media coverage in this leading nuclear nation.

2. Earlier Studies and Purpose of This Study

Media outlets in France obtain information mainly from the country's nuclear related organizations. However, no detailed reports have been made regarding how information is communicated within France from the nuclear related organizations to the media outlets. Furthermore, no attempts have been made so far to analyze the public relations (PR) departments of nuclear related organizations as sources of information for French media outlets.

Meanwhile, some analytical studies and research of the media coverage of the Fukushima Nuclear Accident have been reported in Japan. Examples of such studies and published research findings include a comparison of the coverage of the accident by major newspapers in the United States, the United Kingdom, France, and China [1]; an analysis of the editorial content of the *Asahi Shimbun* over the course of one month after the Fukushima Nuclear Accident [2]; an examination of how journalism functions in Japan by focusing on televised coverage of the accident in its immediate aftermath [3]; and a report on the findings of surveys conducted with people affected by the accident regarding their attitudes towards the media coverage combined with the presentation of problems observed with journalism [4]. Nonetheless, none of these studies targeted the nuclear utilities that provide information to the media outlets.

Against this background, the author visited four nuclear related organizations in France in June 2012 to request interviews with their PR departments. The interviews were conducted as a part of an investigation financed by a JSPS Grant-in-Aid for Scientific Research. These individual interviews were aimed at finding out how nuclear related organizations in France handled public relations when the Fukushima Nuclear Accident occurred and what kinds of attitudes the PR staff adopted when they communicated with journalists. This qualitative study is expected to identify implications and lessons for the performance of PR activities during a nuclear emergency in Japan.

The author has already interviewed some PR staff employed by nuclear utilities, with most of them working for electric power companies in Japan in 2008 [5]. Interviews are exploratory and problem-finding methods for revealing complexity and details. This study adopted the same method as the one used in a study conducted in 2008. In other words, informal interviews were conducted to obtain as much information from the respondents as possible without interrupting their responses from one topic to another. The interviews were also semi-structured to enable the details and order of prepared questions to be flexibly changed [6]. In this manner, a certain degree of freedom was allowed to encourage open-ended responses. These interviews lasted until both sides felt that the ice had been sufficiently broken after the initial encounters.

II. Overview of Media Outlets in France

Let us first take a brief look at the prevalence and history of French newspapers and television broadcasts. As of 2009, about 9.76 million newspapers were published every day in

France, which works out as 193 newspapers being read per 1,000 adults throughout the country. However, Japan publishes many more newspapers than France and other countries around the world, with a total of 50.04 million copies a day working out as about 460 newspapers being read per 1,000 adults. Nevertheless, newspapers remain an important source of information in France, which ranks high in terms of the number of copies published.

Initially, radio and television broadcasts used to be managed centrally by the Office of French Radio and Television (ORTF), which was later split up into seven independent broadcasters in 1974. Compared to Germany and the United Kingdom, however, radio and television broadcasts in France can hardly be described as truly independent following more than half a century of national monopoly [7)].

French journalists approach their sources of information individually. Compared with other citizens, they have special rights stipulated under the law and other regulations. Unlike their Japanese peers, who enjoy no special protections concerning their rights, French journalists have their “spiritual freedom” (autonomy) protected by a labor code. In other words, French journalists have a legally protected status.

III. Overview of Interviews with PR Staff

1. Targets

In June 2012, the author requested individual interviews with major nuclear related organizations in France, as summarized in **Table 1**. Seven individuals from the PR departments at four organizations (AREVA, EDF, CEA, and IRSN) were interviewed. They included three managers. Each person was interviewed for at least one hour at their headquarters in Paris or in the suburbs of Paris.

2. Question Design

The questions asked in the interviews are presented in **Table 2**. First, the interviewees were asked what kind of system the PR staff adopted at their nuclear related organizations to communicate with journalists and what kind of organizational structure they adopted to handle public relations (Category 1). Next, they were asked how they communicate with journalists and what kind of relationships they have with them (Category 2). Later, they were asked whether the characteristics of the media coverage of the Fukushima Nuclear Accident had

Table 1 Respondents to interviews conducted in 2012

Target organization	Respondent	Month/Day (Hours)	Venue
AREVA	1) PR and press officer	6/19 (1.5)	HQ (Paris)
EDF	1) PR and press section chief 2) Press officer	6/21 (1.5)	HQ (Paris)
CEA	1) Press manager 2) Assistant press manager	6/21 (2)	Centre de Saclay (France)
IRSN	1) Press manager 2) Information and media officer	6/22 (1)	Fontenay-aux Rose (France)

Table 2 Interview questions

Category	Question
Category 1: Method of sharing information with media outlets	→ What kind of PR system was adopted at your organization and were you able to swiftly communicate with journalists in the event of an emergency?
Category 2: Method of sharing information regarding the Fukushima nuclear accident with media outlets	→ Do you think that information regarding the Fukushima nuclear accident was shared with journalists based on mutual trust? → Do you think that journalists were satisfied with the information shared by nuclear related organizations regarding the Fukushima nuclear accident?
Category 3: Characteristics of media coverage of the Fukushima nuclear accident	→ Do you think that media coverage of the Fukushima nuclear accident was exaggerated, negative, or sensationalized?
Category 4: Nuclear phase-outs in neighboring countries	→ Do you think that the nuclear phase-outs in neighboring Germany and Switzerland have influenced your organization's PR engagements with media outlets?

Table 3 Summary of interview responses

Question	AREVA	EDF	CEA	IRSN
System adopted by the organization to facilitate information sharing	Emails were sent out simultaneously to about 4,000 registered journalists. The journalists' questions were responded to around the clock. An emergency procedure was implemented to collect information.	A contractor sent information to all of the journalists in one go. The journalists' questions were responded to around the clock. A crisis room was established.	Information was shared with AFP as necessary. The journalists' questions were responded to around the clock. A crisis team was established.	Information was shared with AFP as necessary. The journalists' questions were responded to around the clock. An emergency procedure was implemented to collect information.
Mutual trust with journalists	Transparency was emphasized in responses to journalists, which probably allowed us to gain their trust.	EDF tried to enhance the transparency and reliability of its information, which probably encouraged the journalists to trust it.	As a national research institute, CEA was probably trusted by journalists.	As a national nuclear watchdog, IRSN was probably trusted by journalists.
Satisfaction among journalists	There was too much information. Journalists may have felt that it was heavily loaded with jargon.	A lot of jargon was explained using simpler words. This most likely satisfied the journalists.	Very little organized information seems to have been made available.	We believe that journalists were supplied with enough information for them to be able to write their news articles.
Characteristics of media coverage of the nuclear accident	We don't think that the media coverage was exaggerated.	We don't think that the media coverage was exaggerated.	We don't think that the media coverage was exaggerated.	We don't think that the media coverage was exaggerated.
Phase-outs in neighboring countries	France would suffer a considerable loss from a nuclear phase-out. The policies of neighboring countries won't affect our PR activities.	The nuclear policies of neighboring countries won't influence our PR activities as long as people understand how a phase-out would impact their electricity bills and the global climate.	The decisions made by neighboring countries won't impact our PR activities.	This is just a political decision made by Germany. It won't influence our PR activities in France.

been excessive (Category 3). Lastly, they were asked how they perceived the nuclear phase-outs in neighboring Germany and Switzerland (Category 4).

IV. Interview Results

The responses from the four organizations were compiled by identifying some common elements. **Table 3** summarizes each organization's responses in four question categories.

1. System for Sharing Information with Journalists

The four organizations have all adopted systems that allow their PR staff to share information with journalists directly. This strikes a contrast with the Japanese practice of indirect contact with journalists through press clubs.

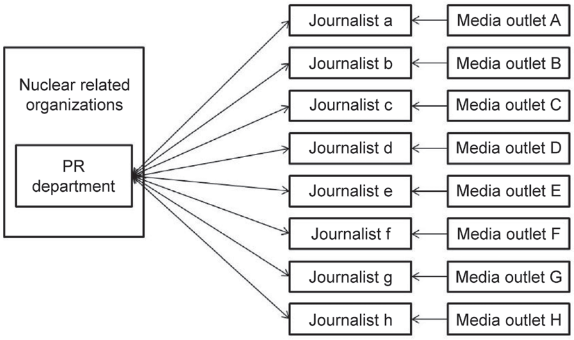

Figure 1 Transmission of information from nuclear related organizations to media outlets in France

Figure 1 shows the typical transmission of information to media outlets in France. AREVA has registered some 4,000 journalists, all of whom can be contacted simultaneously through the sending of mass emails and the like. EDF outsources key communication with journalists to contractors. Both AREVA and EDF have assigned about 10 personnel to deal with journalists. As a research institute, CEA has established a PR system for sharing information with individual journalists only as necessary. Press releases issued by CEA mobilize the network of AFP, a news agency that is one of the leading media organizations in France. IRSN adopts a similar system to that of CEA. Instead of voluntarily sharing information with specific journalists, they have a policy that involves responding to questions from journalists.

Three of the four organizations have employed former journalists as PR staff. All of the four organizations are headquartered in Paris or the suburbs of Paris, and the PR staff working there work together with branch sites located at nuclear facilities and the like. The branch site personnel do not make independent judgements if an accident or other problem occurs on site. They always contact their headquarters first to establish a policy for handling the requisite public relations.

2. Communication with Media Outlets

The responses made by these four organizations varied very little and exhibited certain tendencies. It was noticeable that the PR staff often made statements such as the following: “Even a severe nuclear accident won’t lead the public to believe that France doesn’t need nuclear energy” and “Journalists won’t cast away their perceived need for nuclear energy.” The four respondents all explained that, after the Fukushima Nuclear Accident, they communicated with journalists while keeping in mind the three key points of transparency, credibility, and pedagogy.

They all placed an emphasis on transparency as they contacted journalists regarding the Fukushima Nuclear Accident. They also mentioned that they saw no reason to arouse distrust among journalists. Their responses could also be distilled to arrive at the conclusion that “the media coverage of the Fukushima Nuclear Accident did influence public opinion.” All of the respondents commented that the information shared from Japan in the wake of the Fukushima Nuclear Accident was “sufficient in amount, but sometimes difficult to understand.” They also pointed out that the PR staff could explain how the emergency unfolded once the information from Japan had been processed and sorted out in a clear manner. For this reason, the six respondents shared the view that “Journalists were generally satisfied with the information that they obtained.”

3. Characteristics of Media Coverage of the Nuclear Accident

The PR staff from AREVA, EDF, and CEA all responded by stating that the media coverage of the Fukushima nuclear accident was “not exaggerated” and “had not been sensationalized.” Meanwhile, some responded by saying that “Exaggeration in media coverage is generally inevitable” and “Journalists probably also think that sensationalism is an unavoidable part of media coverage.”

4. Nuclear Power Phase-Outs in Neighboring Countries

The responses were aggregated to form the view that “communication with French media outlets won’t be influenced” by nuclear power phase-outs in Germany and Switzerland. Similarly, the responses were almost identical in expressing the belief that “policies in neighboring countries will not change the perceptions of French journalists on nuclear energy.”

V. Analysis of Responses

In Japan, nuclear utilities have been expanding and strengthening their PR units based on their earlier experiences of conducting PR activities in response to emergencies. In France, however, the PR departments responsible for dealing with media outlets are not as large as their Japanese counterparts are. Furthermore, with the media not having to rely on press clubs in France, the PR staff there evidently and consciously shared information with individual journalists as professionals.

Regardless of any differences in the approaches taken compared to Japan, the PR departments of French nuclear related organizations placed great importance on communicating with media outlets following the Fukushima Nuclear Accident. For this reason, they have established crisis rooms and implemented other robust measures in anticipation of inquiries from citizens and media outlets. These departments anticipated the prominent media coverage of the Fukushima Nuclear Accident.

The interviews also revealed evidence that communication between the PR staff and journalists there was continued with little friction. The staff maintained a good rapport with the media outlets and gauged that the journalists were aware of the need for nuclear energy. In this manner, the interviews demonstrated that French nuclear related organizations tried their best to share information with the country’s media outlets by collecting information regarding the nuclear accident that took place overseas in Japan.

Nonetheless, the PR staff stressed that they sometimes found it difficult to provide adequate explanations to the French media outlets if they did not receive clear information from Japan. In fact, a huge amount of information released by the Tokyo Electric Power Company (TEPCO) reached France, but the quality proved problematic for the PR staff. Any complicated and highly technical information from Japan had to be digested by them to produce clearer explanations.

Descriptions of the PR systems and risk communication employed during emergencies are provided in reports that were submitted in Japan in July 2012 by both the National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission (NAIIC) and the Government’s Investigation Committee on the Accident at the Fukushima Nuclear Power Stations of Tokyo Electric Power Company. Detailed accounts of the PR system employed by TEPCO and their press releases are also found in these reports. Unfortunately, the reports did not mention the importance of delivering relevant information to other countries and communicating with foreign organizations. As far as the findings from this study are concerned, the relevant organizations in countries other than Japan are also compelled to collect information on nuclear accidents. Moreover, attention must be paid to both the amount and quality of the information shared with other countries. Today, nuclear utilities are expected to engage in nuclear public relations to share clear information with foreign nuclear related organizations quickly.

Viewed from the opposite perspective, nuclear utilities must be prepared for the possibility that the impact of a nuclear accident or problem in another country may affect the nuclear policy of their own country. Nuclear utilities are expected to establish PR systems that allow them to provide expert insights in a clear manner to media outlets while earnestly collecting information on nuclear accidents and other relevant events in other countries. Advancements in information technologies are expanding the global reach of the media. With this in mind, nuclear utilities should consciously pursue clear and swift communication with other countries.

VI. Conclusions

The Fukushima Nuclear Accident that occurred in Japan received prominent media coverage in France. Day and night, the PR staff in France skillfully continued to communicate with journalists. This is probably because of the extensive interest that French media outlets have in relation to the use of nuclear energy both in and outside their country, which promotes nuclear power development. Even if a nuclear accident takes place in another country, the value of news can be enhanced by media outlets that operate in countries that use nuclear power. The Fukushima Nuclear Accident showcased this point.

Beck [8)] proposed the idea of a global risk society as risks began to cross borders around the world. As the society faces global risks of a universal nature, information concerning an emergency in one country should be shared swiftly and clearly not only within that country but also with other countries. Nuclear utilities are also expected by nuclear related organizations in other countries to provide information. Whether they are living up to this task has come under international scrutiny.

In particular, proactive information sharing could make a policy contribution to Brazil, Russia, India, China, and South Africa (BRICS), all of which are pursuing nuclear power development, as well as Poland, Romania, the Czech Republic, Lithuania, and other countries that have committed to building nuclear power plants. Going forward, information sharing with other countries should be included in PR activities. Conversely, if a nuclear facility or the like is affected by an accident or problem in another country, Japanese nuclear utilities should try to swiftly provide relevant information to domestic media outlets.

As Combs and Slovic [9)] have pointed out, people gain a recognition of the risks involved through frequent media coverage. Fukuda [10)] upheld the belief that the variables of media coverage cannot be overlooked in discussions of risk communication. Today, information is transmitted across borders in real time. Once nuclear related organizations become capable of swiftly sharing clear information with domestic and foreign media outlets, they will surely advance a step further toward more effective risk communication.

I hope that the findings from this study conducted with PR staff based in France can be complemented by further studies to examine the relationships between nuclear related organizations and media outlets in Asian countries that pursue nuclear power development.

I would like to express my deep gratitude for all of the support that I have received in compiling this study, especially the valuable comments made by reviewers from ATOMOΣ (Journal of the Atomic Energy Society of Japan) and the valuable advice from Mr. Hiroshi Kimura of the non-profit organization Public Outreach, and Mr. Tsutomu Sata, Principal Administrator of the PR Department at the Japan Atomic Energy Agency.

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Commentary

How Do the Present Conditions of the Fukushima Daiichi Nuclear Power Plant Turn Out?

−We cannot Continue a Huge Burden−

Journalist, **Takaaki Ishii**

On May 24, 2014, the author visited the Fukushima Daiichi Nuclear Power Plant to interview representatives of the Tokyo Electric Power Company (TEPCO) about the accident that was triggered at their plant by the 2011 Tohoku earthquake and the subsequent tsunami. In contrast to the prevailing social perception of an ongoing crisis at the nuclear power plant, the accident site is shifting away from the coordination of a crisis response under hellish conditions toward the planning and implementation of routine tasks. The accident site has been cleared and turned into a construction site where 5,000 personnel safely carry out their work on weekdays in a composed manner. Nevertheless, the almost excessive implementation of safety measures has raised doubts about whether the construction work really needs to be carried out this way. To ensure that this work can be carried out properly, cost minimization should be taken into account to promote labor and cost savings.

I. Reduced Risks of Escalation

Intense images of scattered debris and the hydrogen explosions that occurred remain seared in the minds of many people who witnessed the Fukushima Daiichi Nuclear Accident unfold. Media outlets commonly stress danger and fuel a sense of fear. Nonetheless, the author did not feel any fear when he visited the accident site. Although hazards remain, they have been identified and addressed by appropriate measures. They are no longer out of control.

Responding to a request in the on-site interview for a description of the current situation from the perspective of his role as the Chief Decommissioning Officer, who is also responsible for measures against contaminated water, Mr. Naohiro Masuda, TEPCO’s Managing Executive Officer, had the following to say.

Even if an earthquake and tsunami comparable to the one that hit the east coast of Japan in 2011 were to happen, an escalation of the accident involving the release of radioactive materials is less likely now. Certainly, we still face mounting challenges, but we would like people to know that steady improvements have been made.

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Following his visit to the site, the author also agreed with this view on the current situation.

Let us take a brief look back at some of the Fukushima Daiichi Nuclear Accident. The power plant had six reactors, and Units 1 through 3 had been in operation before their emergency shutdown was prompted by the earthquake that struck East Japan. The subsequent tsunami flooded the plant extensively. The flooding of buildings and loss of power made it impossible to cool the three reactors that had been in operation. Their nuclear fuels melted and the reactor at Unit 2 suffered damage, which led to the release of radioactive materials. The reactor buildings for Units 1, 3, and 4 were partially damaged in the explosions caused by leaking hydrogen.

Three years on, the situation has been improved remarkably through construction work. The damaged top of Unit 1 has been covered and the major release of radioactive materials has been almost fully contained. Each reactor is cooled by injecting water to maintain a cold shutdown.

In each reactor, the spent fuel had been kept in a pool situated in the same building. However, in the immediate aftermath of the accident, these pools were vulnerable to potential damage from another earthquake and a subsequent release of radioactive materials. Some of these pools have now been reinforced to manage the fuel they contain safely.

Construction work has gathered pace. On weekdays, about 5,000 personnel from affiliated companies carry out their work. Furthermore, about 1,000 TEPCO employees are working inside the premises of the Daiichi Nuclear Power Plant or 15 km away at the Daini Nuclear Power Plant to facilitate the recovery from the accident. About half of the personnel from affiliated companies and TEPCO employees are Fukushima residents.

In principle, all of the costs incurred due to the nuclear accident must be covered by TEPCO. To bring the accident under control, decommission the reactors, and implement measures against contaminated water, TEPCO has posted an extraordinary loss of 970 billion yen up to March 2013. They have not used up their entire budget yet, but the annual expenses for these tasks is expected to amount to several dozen billion yen.

TEPCO has effectively been nationalized with more than half of the capital being injected by the state-backed Nuclear Damage Compensation Facilitation Corporation. This fund has been helping the power company to pay compensation for the nuclear accident. This August, the fund will be replaced by the Nuclear Damage Compensation and Decommissioning Facilitation Corporation to provide financial support for efforts to recover from the accident and decommission the reactors. The completion of this work is expected to take a very long time, perhaps even as long as 30 to 40 years from when the accident struck.

II. Strict Protective Measures Against Radiation

During his visit, the strict radiation controls that were employed there left a striking impression on the author. The following is an overview of what he experienced there.

Hirono is a town in Fukushima Prefecture that is home to J-Village, the National Training Center of Football. Situated about 20 km from the Fukushima Daiichi Nuclear Power Plant, this center is now being rented by TEPCO to serve as a base for efforts to recover from the accident. Before anyone leaves the center for the plant and then later returns to the center, their internal exposure to radiation is measured using a whole-body counter that is installed there.

The author took a bus from the center to visit the Fukushima Daiichi Nuclear Power Plant. As he travelled north on National Route 6, he noticed that most parts of Naraha, Tomioka, and Okuma in the Futaba District were visibly deserted. These places were still designated as difficult-to-return zones or restricted residence zones. The houses there were being overgrown with thick green vegetation. The sight of these crumbling communities caused the author great distress.

The plant could be accessed through only one point. Furthermore, photography was restricted on the premises. The author went through a metal detector and completed the identification procedure before entering the plant, at which point he was handed a personal dosimeter. All these are probably for a precaution against terrorism.

Thanks to the progress that has been made in decontaminating the site, the work there is becoming less hazardous. The radiation doses vary from one spot to another, though. In the immediate aftermath of the accident, it was quite common for the on-site dose to be several hundred microsieverts per hour. Now, however, the dose has mostly been brought down to a few microsieverts per hour. The author's visit lasted for one and half hours, most of which was spent on a bus and a little bit on foot. The resulting dose amounted to 20 μSv, which is not much compared to a regular dose of 50 μSv from one X-ray examination. Nevertheless, people must still stay away from some spots near the reactors to avoid a high radiation dose.

At the site, the author wore the same outfit as the workers there. On top of the undershorts and T-shirt that he was provided with, he wore a one-piece protective garment called a Tyvek coverall. Part of this protective garment is made of transparent vinyl that allows the gate attendant to check that everyone is carrying a personal dosimeter and an ID card, which were often forgotten. The garment does not shield against radiation, but it protects the skin from any contact with radioactive materials.

After that, the author put on a paper cap, a rubber mask and a helmet. The mask was equipped with a filter at its tip to remove radioactivity. This mask provides protection against the inhalation of contaminated materials so it cannot be removed in some designated zones on-site. Before walking in some potentially contaminated areas, the author put on work shoes that were further protected with plastic shoe covers. The author removed these plastic covers each time he entered a building or a bus to avoid further contamination from shoes.

The protective outfit is light enough and normal movements can be performed without any discomfort. After you have taken a few breaths through the mask, the perceived difficulty in breathing soon fades away. However, the summer heat remains a problem. Workers can be provided with coolants, but they say it is still difficult to perform heavy work for a long time. It was explained to the author that these protective measures are taken just in case, not because the environment is hazardous. In fact, no visitor has inhaled or touched any radioactive substances. Such an incidence is also rare among workers.

The author was additionally examined twice with dosimeters before he left designated zones at the site to check for exposure. If someone is exposed to an excessive amount of radiation, they undergo a decontamination process followed by a medical diagnosis and treatment by a medical doctor. As of today, no one has experienced a large enough exposure to warrant receiving any such treatment.

At some on-site locations, the radiation doses from about 50 spots were displayed in real time to encourage those inside to take the necessary precautions. Such on-site measurements made it possible for individual daily exposure doses to be predicted. If the actual dose ever exceeds the predicted level, an investigation is carried out to identify the contamination source.

The individual exposure doses of workers and TEPCO employees are recorded as database.

Figure 1 A view of the inside of the Unit 4 reactor building, where the spent fuel pool was feared to have broken open
Aseismic reinforcement has been completed for the pool and the spent fuel is being removed. Visitors can observe the work conducted there as long as they are wearing protective garments and masks. (Photo credit: Noriyuki Inoue, WEDGE)

TEPCO provides the workers, TEPCO employees and managers with this information once a month or if their exposure doses exceed the expected levels by a wide margin. It is very difficult to check the several thousand persons who enter the premises every day, but the necessary procedure is automated as much as possible. The statutory exposure dose limits are now back to the normal levels that applied before the accident; in other words, a maximum of 100 mSv in five years and 50 mSv in a year. Any person who reaches these limits is no longer allowed to work at the Fukushima Daiichi Nuclear Power Plant or to carry out any other work that may entail exposure to radiation. Such strict controls leave only a small possibility of workers at the nuclear power plant suffering any health damage.

III. Resolution of Imminent Danger of Damage to Spent Fuel in Unit 4

Let us move on to describe what the situation looked like on-site. The author first entered an important anti-seismic building. During the accident, the central command here was connected to the TEPCO headquarters via a communication line for video-conferencing. It was a well-known place because of the media coverage. After the hydrogen explosion, the plant manager Masao Yoshida and his fellow TEPCO employees remained on-site at the command center, prepared to die if necessary.

However, the building is by no means a historical relic. It is still in use and over a hundred people work in this vast command center. Officers assigned from the Agency for Natural Resources and Energy, the Nuclear Regulation Authority, and the Fukushima Prefectural Government are stationed there, and meetings are often convened there too.

The building also provides a resting place for workers. TEPCO plans to build a new resting facility and an administration building at the site in the near future. The old administration buildings were destroyed by the tsunami.

Letters and messages of encouragement from people in Japan and abroad, such as “Hang in there” and “The whole of Japan is rooting for you,” have been neatly posted along the whole passageway together with hand-folded paper cranes to boost the morale of workers and TEPCO employees. There were many posters in different spots calling for safety checks, because the building also functioned as the construction site office.

After changing into his protective outfit, the author observed the site while travelling around on a bus. He was taken inland to an elevated spot that commands a panoramic view of the four reactor buildings. Photographs of these reactors were taken from this spot during the accident. Today, all of the reactors have been cleared up and the damaged parts have been covered.

Later, the author entered the reactor building for Unit 4. The fourth and fifth floors of this building were blown away by the hydrogen explosion. There were fears that radioactive materials may be released from the spent fuel stored in this building. Fortunately, the spent fuel pool retained water so it could sustain its cooling function.

TEPCO has since reinforced the building and the pool. They have also built a giant steel structure on adjacent land. This structure has been equipped with a horizontal extension consisting of an iron frame to set up a crane in a reversed and tilted L-shape.

The reactor in Unit 4 has been reinforced using 4,200 tons of steel, which is almost comparable to the amount used for Tokyo Tower. The spent fuel has been removed from there since last autumn. The building and the pool have been reinforced with an enormous, robust steel structure, making them seem ready to withstand any earthquake.

When the accident took place, 1,500 spent fuel assemblies were being stored there. Nearly half of them have now been relocated to a dry cask storage facility in the nuclear power plant.

The author took a simplified construction site elevator to go up to the fifth floor. Once there, he gazed into the pool that stored spent fuel assemblies under blue water.

Standing right next to the pool, the author felt a modicum of relief. The object that once terrified the whole of Japan is now back under human control and the hazards have been reduced.

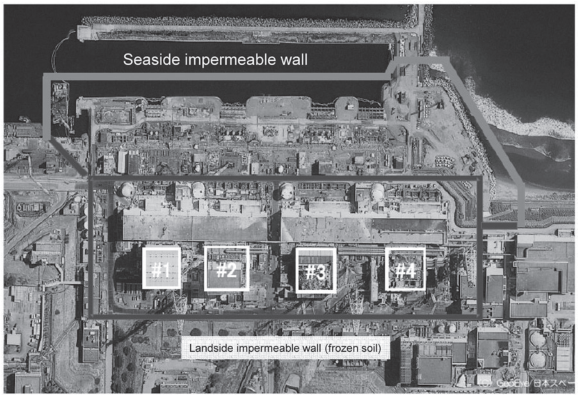

Figure 2 Situation at the premises of the Fukushima Daiichi Nuclear Power Plant and construction of frozen soil walls and impermeable walls
The four reactors will be enclosed to block water from flowing into the reactors (extract from materials provided by TEPCO).

IV. Progress Made in Implementing Measures Against Contaminated Water

Measures are being taken to deal with the contaminated water that attracted public attention. In the immediate response to the accident, the spent fuel and reactors were cooled by discharging water brought in from off-site areas. Immediately after the accident, the reactors were cooled. The contaminated water that these efforts produced has since been removed and stored. Four of the reactors are situated at a lower elevation at the site. The areas surrounding these reactors are estimated to have a groundwater inflow of around 400 tons per day. Rainwater adds to this amount.

TEPCO is currently pumping water up from a well bored on the inland side of the reactors. In May, they began to release this water into the ocean after confirming that it had not been contaminated. Furthermore, the company has begun carrying out simplified pavement (facing) work around the plant to keep rainwater from seeping underground.

TEPCO is also trying to build something called a “frozen soil wall.” A cutting-edge technology is used to freeze underground water by pouring a special chemical into the ground, thereby blocking the flow of water. The company says that their demonstration experiment was successfully completed. In addition, construction work for another impermeable wall situated along the coast has almost been completed with the aim of preventing contaminated water from leaking into the ocean.

On May 24, when the interview was conducted, TEPCO resumed operation of its multi-nuclide removal equipment (ALPS). This equipment removes 62 types of radionuclides from the water used to cool reactors as well as from water that has seeped inside the reactors and been contaminated with radioactive materials. In June, the operation of three such units was begun. In the future, the volume of contaminated water treated per day is expected to reach 750 tons.

The vast ALPS resembled a chemical plant, and its top was covered with a tent. According to a TEPCO representative, they are trying to separate contaminated groundwater from rainwater. The radioactive materials are removed from the water by using special filters.

TEPCO is storing all of the contaminated water in tanks on the plant premises because they have been unable to obtain consent from fishery operators and local residents to discharge the water elsewhere. Currently, a whopping 500,000 tons of contaminated water is being stored at the plant. One thousand huge tanks of various different shapes have been constructed there, and some new tanks with a height of about 10 m were being constructed at various places on-site.

Given that Unit 1 still has high radiation levels and work was underway there, visitors could not approach it. Thanks to the enormous cover on Unit 1, the dispersion of radioactive materials into the atmosphere has been curbed. The building has now been cleared up, and progress is gradually being made in relation to examining the damaged reactor by deploying robots and the like.

V. An Almost Unimaginable Tsunami in the Calm Ocean

At the coast, the author observed the devastation left by the repeated tsunami waves that reached a height of roughly 15 m. The concrete seawalls there, which probably stood several meters tall, were destroyed across the board, demonstrating just how powerful the force of the

Figure 3 The enormous multi-nuclide removal equipment (ALPS) seen during the interview (Photo credit: Noriyuki Inoue, WEDGE)

tsunami was. Provisional coastal protection facilities were being constructed with Tetrapods to prepare for the possible arrival of another tsunami.

The coast could not be approached due to the ongoing construction work there, but the wreckage had already been cleared away. Nevertheless, traces of mud were still visible even on buildings located quite far away from the coast. Some of the wreckage had been piled up and left untouched at the side of the road here and there.

The author found it hard to imagine that the calm, blue ocean visible from the power plant could have caused that tsunami. Since the accident, TEPCO and the Nuclear and Industry Safety Agency, which was the regulatory authority at that time, have been criticized for their inadequate anticipation of tsunamis. However, the author felt that the usual calmness of the ocean would have understandably made it difficult for them to anticipate such a massive tsunami.

Media outlets in Japan and abroad commonly fuel fears concerning the Fukushima Daiichi Nuclear Power Plant by focusing on negative news about unsuccessful measures. The author believes that they do not accurately report the current situation. Admittedly, dangerous spots remain and small mistakes are occasionally made, but the risk of an accident escalating has been reduced. The author felt nothing but gratitude and respect toward all of the people engaged in this enormous and painstaking effort.

VI. Are the Efforts Having a Tangible Effect?

Having observed the comprehensive efforts being made on-site by TEPCO, the author harbored some doubts about their adequacy in terms of costs versus benefits. The company seems to be pursuing safety by implementing excessive measures without any clear sense of purpose to the procedures.

The future of the whole of Japan depends on the work carried out to bring the accident under control. The Japanese government also allocates a budget for these efforts. Everyone would agree with the goal of eliminating the health damage caused by the accident. Naturally, the work to recover from the accident should focus on safely controlling the radioactive materials contained in the reactors, especially with respect to the treatment of the nuclear fuel in Units 1 to 3 as they experienced a meltdown. TEPCO is addressing the hazard there as well.

The author could clearly see, however, that the company was devoting too much of its personnel and other resources to measures against contaminated water.

Currently, the health of nearby residents has barely been affected by the nuclear accident. The government of Japan, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and the International Atomic Energy Agency (IAEA) as well as experts from Japan and abroad commonly estimate that the accident has caused only negligible health damage to the residents of Fukushima Prefecture and the rest of the country. In fact, the health of the residents of Fukushima Prefecture is being harmed by their prolonged evacuation from the areas surrounding the nuclear power plant. Given the reality of the situation, the purpose seems unclear with excessive safety measures being implemented for the construction work. Enhanced safety levels incur increased costs.

One example of this is the issue of contaminated water. TEPCO is storing all of it in tanks, so their vast premises were packed with storage tanks.

Radioactive materials leaked into the ocean immediately after the accident. Today, however, there is no major leakage of contaminated water. Even if some contaminated water did leak out, it would be diluted by the seawater. Furthermore, there is only a marginal chance of it affecting human health through marine creatures and seawater.

Experts from Japan and other countries recommend that TEPCO release the contaminated water into the ocean after removing any nuclear materials and making sure that it will have no impact on human health. Although current technologies are unable to separate tritium from water, this radioactive isotope poses little harm to the human body. However, even if this isotope can be left in the water, the government and TEPCO are still cautious about a release into the ocean. Meanwhile, TEPCO keeps on building tanks. Naturally, local residents and fishery operators are wary of contaminated water being spilled into the ocean. However, there is no sign of any proactive efforts being made by the government to persuade stakeholders of the safety of a marine release and to coordinate with them on it.

When the author asked Mr. Masuda, TEPCO’s Managing Executive Officer as well as its Chief Decommissioning Officer, why the company could not safely treat the contaminated water by releasing it into the ocean, he responded by saying that TEPCO cannot take such a decision alone. This is probably because the company is managed by the government, and their responsibilities have not been clearly assigned for the ongoing construction work. The decision-making is perhaps being slowed down by concerns and reservations, while the costs borne by TEPCO continue to pile up.

The Japanese government’s support has been inconsistent. The frozen soil wall was created to block contaminated water with national support amounting to 47 billion yen. The funds for this work were disbursed from a discretionary reserve from the budget for fiscal 2013, which does not require a detailed audit by the Diet. In autumn 2013, during Japan’s bid to host the Olympics in Tokyo, the issue of contaminated water drew attention. To dispel domestic and international concerns over this issue, Prime Minister Shinzo Abe remarked at both the IOC general meeting and other domestic events that “The government is taking the reins and will completely resolve the matter.” That was how the government came to take the lead in allocating a budget to deal with contaminated water.

However, work conducted as part of efforts to recover from the nuclear accident has been assigned to TEPCO as a private company. Since taxpayers’ money cannot be spent on civil engineering work carried out by private companies, discretionary reserves have been spent in the name of providing assistance for research and development with exceptional approval from the Ministry of Finance. This is how the construction of the frozen soil wall was decided on as an advanced technical solution. In contrast, the construction of tanks, pavements to block rainwater, and other low-tech measures cannot be covered by taxpayers' money.

In 2013, the International Research Institute for Nuclear Decommissioning (IRID) was established under an initiative of the Japanese government and with support from TEPCO and other companies to lead technical research into the Fukushima Nuclear Accident. At the institute, experts on decommissioning and measures against nuclear accidents were brought together from different countries to form an international advisory team and offer advice on recovering from the accident. The author interviewed one of the team members. The interviewee had a high opinion of the work that had been carried out since the Fukushima Nuclear Accident and felt that it had generally been conducted appropriately.

However, it is important to note that the interviewee also said, "More than one plan should be prepared so that alternatives can be tried out flexibly if one approach doesn't work. Also the cost and effectiveness should be carefully nailed down." Asked if TEPCO is failing to do this, the interviewee answered by saying, "That is not the case." Perhaps the interviewee also questioned the way in which the construction work is prioritized.

Nevertheless, it would be unfair to assign all of the blame to TEPCO. The government has to accept a considerable amount of responsibility for this matter. TEPCO's operations are supported by the Japanese government through both capital injections and assistance from national institutes. Overly concerned with public opinion, the government has continually opted to implement excessive safety measures in dealing with the accident rather than adopting the recommendations of experts.

Such policies have been adopted in relation to various matters, including the decontamination efforts in Fukushima, the management of radioactive materials, and food sanitation. These policies have produced various detrimental effects. The same can be said with respect to efforts to recover from the accident and decommission reactors. A clear line must be drawn in relation to acceptable costs for the measures carried out by TEPCO, while the government mediates between stakeholders to dispel their concerns.

TEPCO cannot continue to incur costs without limit. Decisions must be made concerning who does what, which tasks should be prioritized, and which tasks should be omitted to save costs. TEPCO continues to sell electric power, and the costs that they incur are passed on to the people of Tokyo and its surrounding regions in the form of higher electricity bills. Taxpayers must shoulder a greater burden to enable the government to support TEPCO with their money.

VII. Concerns Over Morale Among Workers

In a tale similar to that of Sisyphus and his rock, Japanese Buddhist folklore speaks of souls in the underworld being forced to build a pile of pebbles only for the pile to be maliciously knocked down by demons. A modern day equivalent of this is the effect that repeatedly carrying out construction work to recover from the accident without a clear purpose could have on the morale of workers.

A range of construction work has been carried out through a partnership between TEPCO and its affiliated companies. TEPCO plans to offer longer-term contracts to workers from its affiliated companies to make it easier for them to gain the requisite skills. The company also intends to build a resting space to create a more conducive work environment. Workers are paid quite well for their work, with some receiving tens of thousands of yen per day depending on the tasks that they perform.

However, employees of TEPCO, as the entity responsible for the accident, continue to face a harsh situation. In any conversation with the author, every TEPCO employee in Fukushima expressed remorse for the accident and pledged to rebuild the area. TEPCO's Executive Vice President Yoshiyuki Ishizaki, who heads the Fukushima Revitalization Headquarters, said the following: "TEPCO will face up to its responsibility for having caused this terrible accident. Personally, I will devote my entire life to the reconstruction of Fukushima." Mr. Naohiro Masuda, the Managing Executive Officer in charge of decommissioning, vowed to maintain the company's rapport with its affiliated companies as part of its efforts to recover from the accident and reassure the people of Fukushima.

This sense of commitment is certainly admirable, but it also felt a little painful to the author. Can individual employees shoulder the responsibility for an accident that was caused by their company? Certainly, some people would still feel responsible for the accident that took place three years ago. However, it is unconceivable for the whole company and individual employees to continue holding on to this sense of responsibility for several tens of years.

The Japanese government and TEPCO have presented a medium- to long-term roadmap for the decommissioning work. The last step of this decommissioning is not clearly defined and its completion is expected to take 30 to 40 years from the time of the accident. Can workers really shoulder this responsibility for that long?

People from Fukushima harbor mixed feelings toward TEPCO, and they certainly feel a certain amount of anger. More than anything, though, they "cannot afford to speak ill of others during their struggle to survive each day" (according to the female leader of a local NPO).

Evacuees from areas designated by the Japanese government receive a compensation payment of 100,000 yen per month for the psychological pain that the accident inflicted. Before the accident, the local construction industry and many other community members used to receive orders from TEPCO for work related to operating the plant. They now perform jobs related to recovering from the accident. In this respect, TEPCO is an important member of the local community.

"Why don't you visit the residences of TEPCO employees to cover the conditions there? They are in a sorry plight." That was a suggestion made by the woman from the NPO. About 1,000 TEPCO employees of different ages were living in an array of prefabricated company dormitories built on the J-Village football pitch. They resemble temporary offices at a construction site.

The area is partitioned into spaces with an area of a dozen square meters where each worker can sleep and live. Apparently, many of the workers repeatedly eat breakfast and supper at the staff canteen and bring lunchboxes to work. The living conditions at the dormitories are kept to a bare minimum probably in light of public scrutiny of the company responsible for the accident. TEPCO employees live in such a harsh environment and carry out strenuous work aimed at recovering from the accident under enormous pressure.

VIII. Necessary Considerations for Minimizing Costs

When the Fukushima Nuclear Accident occurred, the then government formed by the Democratic Party of Japan pinned the responsibility on TEPCO while allowing the company to stay in business. Such inconsistent decisions may have been inevitable considering the strong criticism that TEPCO was subjected to in the immediate aftermath. However, it is high time we assessed the positive and negative aspects of the measures taken to deal with the consequences.

Today, the key to handling the accident is minimizing the labor inputs and costs. At the site, the enormity of the construction work catches your attention, but its effectiveness is probably not really scrutinized. This vast construction work may reach an impasse unless the financial burden, roles, and responsibilities are limited to acceptable levels for TEPCO and the public.

If this work continues without any clear goals in sight, the prevailing public mistrust and anxiety over nuclear energy will continue to go unaddressed. This will certainly continue to have an adverse effect on the future of nuclear energy in Japan.

Since the immediate aftermath of the nuclear accident, fear and unfounded rumors have thrown society into disarray and obstructed cool-headed decisions on various issues. With three years having passed already, rational decisions must be made in relation to handling the accident by assessing the current realities at the nuclear power plants in Fukushima.

TEPCO cannot draw a clear line for acceptable costs on its own. The process must be led by the government. Specific actions can be taken by Prime Minister Shinzo Abe and the governing Liberal Democratic Party. Furthermore, it is our voices as citizens that will prompt the necessary decisions.

Commentary

Toward Enhancing Preparedness and Response Arrangements and Capabilities for a Nuclear Emergency(1)

−Emergency Preparedness and Response “Concepts in International Standards and Fukushima Experience”−

Japan Atomic Energy Agency, **Toshimitsu Homma**

The Nuclear Regulation Authority (NRA) has enacted the Guide for Emergency Preparedness and Response (hereafter, “NRA EPR Guide”) by taking heed of the lessons learned from the Fukushima Daiichi Nuclear Power Plant (NPP) Accident in line with international standards for emergency preparedness and response that were established mainly by the International Atomic Energy Agency (IAEA). This commentary explains the safety requirements established by the IAEA, along with the underlying basic concept of the protection strategy for an emergency response.

I. Introduction

In March 2013, the Nuclear Safety Subcommittee of the Atomic Energy Society of Japan (AESJ) published a report (subtitled “What Went Wrong and What Should Be Done?”) based on discussions that took place during the eight rounds of seminars on the Fukushima Daiichi NPP Accident that were held in 2012 [1]. To further these discussions, the AESJ held an organized session at its Spring Annual Meeting 2014 to feature challenges involving nuclear emergency preparedness and response as an important means of defense in depth. Nuclear emergency preparedness and response is aimed at fully mitigating the impact of any loss of control at nuclear facilities or radiation sources to protect people and the environment from radiation. Specific measures were discussed in detail through presentations given by experts from various organizations and at the overall discussion session.

The organized session, entitled “Toward Enhancing Preparedness and Response Arrangements and Capabilities for a Nuclear Emergency,” consisted of the following three presentations: (1) Emergency preparedness and response—Concepts in international standards and Fukushima experience, which was presented by Toshimitsu Homma (author); (2) A desirable system for nuclear preparedness and response, which was presented by Yasushi Morishita, Director of the Nuclear Regulation Policy Planning Division, NRA Secretariat; and (3) Current state of evacuation plans and challenges ahead, which was presented by Noriaki Shimada,

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Director of the Office for Evacuation, Nuclear Safety Subcommittee, Disaster Management Department, Shimane Prefecture, followed by the overall discussion chaired by Takashi Nitta from the Japan Atomic Power Company. Commentary (1) provides an overview of the presentation (1), while Commentary (2) provides an overview of the presentations (2) and (3).

II. Lessons Learned from the Fukushima Daiichi NPP Accident and the NRA EPR Guide

An overview of the report published by the Nuclear Safety Subcommittee has already been provided in this commentary series. Addressing challenges associated with nuclear preparedness and response [2)], the fifth commentary drew the following seven lessons from the Fukushima Daiichi NPP Accident in relation to challenges involving urgent and long-term protective actions as well as emergency management and operation.

Lesson 1: Implementation of urgent protective actions: Arrangements should be made to promptly implement precautionary urgent protective actions within a predetermined zone before radioactive material is released into the environment based on predefined criteria for plant conditions.

Lesson 2: Evacuation and sheltering: Prior arrangements should be made to ensure the safe evacuation of persons in need of assistance from special facilities such as hospitals. Sheltering should be implemented only for a short period until such persons can be safely evacuated or relocated.

Lesson 3: Immediate restrictions on food and drink: Operational intervention levels (OILs) should be prepared based on immediately available data, such as ambient dose rates for restrictions on food and drink during crisis management in the early phase of the response.

Lesson 4: Long-term restrictions on food and drink: Practical recommendations should be made concerning long-term restrictions on food and drink with due consideration given to the actual situation in the affected areas and international harmonization.

Lesson 5: Protective actions over the timeline: The concept and criteria for urgent and long-term protective actions should be established, including actions aimed at facilitating the resumption of normal life in the preparedness stage. Such actions should include providing advance guidance on the application of the principles of radiation protection to the possible emergency conditions that correspond to the protective actions.

Lesson 6: Operational intervention levels (OILs): OILs provide essential guidelines for making decisions in an emergency. More detailed international guidelines on preparing OILs are necessary.

Lesson 7: Preparedness against combined emergencies: Arrangements should be put in place for the full range of possible events, including those with a very low probability, taking into account the combination of a nuclear accident with a conventional emergency, such as an emergency following an earthquake.

In line with these lessons, the following practical challenges should probably be considered as well.

- In the aftermath of the Fukushima Daiichi NPP Accident, critical information was not shared among the organizations involved, especially those from the accident site, municipalities, regulatory bodies, and the national government. The assignment of roles and the chain of command must be clarified to ensure information sharing and proper coordination.

- Basically, the national and local governments have roles to play in the off-site arrangements, while the operator has roles to play in the on-site arrangements. Nonetheless, it is important for the operator to coordinate its arrangements with the national and local governments to ensure a prompt and effective response. In addition, both sides may be required to cross such boundaries when considering their roles.
- In the crisis management phase, the initial response should be guided by predetermined methods. At the same time real experts must be trained and constantly deployed to assist the decision makers so that flexible responses can be taken even in unexpected circumstances.
- The fire service, police, Self-Defense Forces, and other emergency response professionals should be mobilized to facilitate evacuation and other protective actions at the scene. Instead of treating nuclear emergencies as something exceptional, local governments can prepare for the necessary operations effectively under the same framework as that applied when responding to other conventional emergencies.
- It is questionable whether a facility in which responders work only in the event of a nuclear emergency will actually function. Consideration should be given to integrating such a facility with one used for responding to a conventional emergency.

One of the major lessons to be learned from the Fukushima Daiichi NPP Accident is that both the operators and the national and local governments made an implicit assumption that such severe accidents could not happen, resulting in them paying insufficient attention to preparedness for such accidents. The Regulatory Guide on Emergency Preparedness for Nuclear Facilities issued by the Nuclear Safety Commission (hereafter, the “NSC Guide”) specified various technical indicators, such as “areas in which arrangements for emergency preparedness and response should be intensively implemented (emergency planning zones (EPZs))” and “criteria for protective actions (dose criteria),” for implementing urgent protective actions. However, this guide did not clarify the concept of operations for protective actions or explain the specific steps required. For this reason, in the emergency response drills that were conducted frequently after the JCO Tokaimura criticality accident, an approach was established in which the areas for evacuation and sheltering were decided by comparing the dose projections obtained using two emergency simulation systems: the Emergency Response Support System (ERSS; source term predictions for accident progress, released amounts, etc.) and the System for Prediction of Environmental Emergency Dose Information (SPEEDI). Although such an approach was different from the basic concept used for implementing the urgent protective actions commonly adopted by the international community, the necessary review of this approach had been neglected.

Immediately after the accident, the NSC established a working group on the Emergency Preparedness Guide under the Special Committee on Nuclear Disaster to discuss issues to be reflected in the NSC Guide. The working group summarized an approach for revising the guide. These revisions were sought in order to take into account the basic concept of protective actions in emergencies in line with the latest international considerations. Moreover, based on the lessons learned from the Fukushima Daiichi NPP Accident, the working group has considered the basic concept of protective actions against all reasonably foreseeable events (even those with a very low probability of occurrence) to protect human life, health, property, and daily life as well as the environment. They produced an interim report in March 2012 [3)].

The NRA, which was established in September 2012, issued the new EPR Guide [4)] in October 2012 based on the review of the NSC Guide and the interim report as well as reports from commissions assigned to investigate the Fukushima Daiichi NPP Accident. This commentary explains the international standards that were taken into account during the process of establishing the NRA EPR Guide.

A particular focus is placed on the basic concept of emergency preparedness and response, as adopted by the International Atomic Energy Agency (IAEA) and the International Commission on Radiological Protection (ICRP).

III. International Standard Developments at the Time of the Fukushima Daiichi NPP Accident

In 2011, when the Fukushima Daiichi NPP Accident took place, the IAEA published two important documents related to nuclear preparedness and response: GSR Part 3 (Interim, 2011)[5)], which is a revised version of the Basic Safety Standards (BSS) issued in 1996 that defined the safety requirements for radiation protection; and General Safety Guide No. GSG-2 in 2011[6)], which defines the "Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency." These documents reflected the ideas behind the new recommendations issued by the ICRP in 2007 (ICRP Pub. 103)[7)]. The concept of radiation protection has evolved from a process-based approach using practices and interventions to an approach based on the characteristics of three kinds of exposure situations; namely, planned exposure, emergency exposure, and existing exposure situations. In particular, guidance for the necessary responses to emergency exposure and existing exposure situations were respectively compiled in 2009 (ICRP Pub. 109[8)] and 111[9)]). In this respect, the year 2011 marked a transition to this new way of thinking about radiation protection. It is fair to say that when the Fukushima Daiichi NPP Accident took place, none of the emergency response plans produced by Japan or any other country had adopted the radiation protection concept for emergency exposure and existing exposure situations after an accident, as recommended by the ICRP.

Nonetheless, prior to the Fukushima Daiichi NPP Accident, the IAEA had developed the safety requirements *Preparedness and Response for a Nuclear or Radiological Emergency* (GS-R-2, 2002)[10)] based on the lessons learned from incidents such as the nuclear reactor accidents at the Three Mile Island (TMI) plant in the United States and the Chernobyl plant in the former Soviet Union, the radiation source accident in Goiânia, Brazil[11)], and the criticality accident in JCO Tokaimura. These safety requirements have been valued by many countries as a basic concept of emergency response. The IAEA is currently revising GS-R-2, which will be published in the near future as GSR Part 7. The discussions held so far have not led to any substantial changes to the basic concept of emergency response, while the requirements incorporate lessons learned from the Fukushima Daiichi NPP Accident and the new concept of radiation protection.

IV. Basic Concept of Emergency Response Adopted in International Standards

1. Overview of the Emergency Management Timeline

In an emergency, various activities are required of operators, local governments, and the national government to effectively mitigate the impacts on the health and infrastructure of local residents as well as the environment and support the return of affected areas to normal social and economic activity as far as possible. In responding to an emergency, it is important for the relevant organizations to establish a common and consistent decision-making scheme throughout the emergency management timeline. **Figure 1** presents the concept of emergency management for each phase along the timeline [12]. In Figure 1, the solid line represents the amount of information or the involvement of stakeholders, while the dotted line represents the level of uncertainty. An emergency can be broadly divided into three stages: preparedness, response, and recovery. The response stage can be further divided into response initiation and crisis management in the early phase and consequence management and transition to recovery in the intermediate phase.

In the early phase, event/response initiation includes recognition of the emergency situation and initiation of the response. Together with measures for mitigating the accident's progression and gaining control over the source, urgent protective actions are implemented from the perspective of crisis management. Owing to the greater uncertainty caused by the limited availability of information during crisis management, an extremely urgent response is required even before reliable information on the emergency becomes available to achieve the radiation protection goal of avoiding severe deterministic health effects and keeping the stochastic health effects as low as reasonably achievable. For this reason, urgent protective actions are taken according to a planned procedure for a scenario assumed in the preparedness stage. The necessary coordination should be undertaken with stakeholders beforehand in the preparedness phase. More information becomes available over time and coordination with stakeholders will be more important during consequence management and the transition to recovery.

In the intermediate phase, consequence management is identified as the period of time after a certain degree of control has been regained over the source or the major release has been terminated and radioactive contamination is in the environment. During this phase, adequate dialogue should be conducted with stakeholders to modify and lift any protective actions taken in the early phase and to consider long-term protective actions, such as restoring agriculture or decontaminating affected areas. These actions should be taken based on an adequate characterization of the radiological situation by environmental monitoring or analysis. In the transition to recovery, specific plans are developed to initiate the recovery/long-term rehabilitation of affected areas, and support is provided to return social and economic activities to normal.

The concept of an emergency exposure situation recommended by the ICRP in 2007 can be adopted in the early and intermediate phases of a response. Similarly, the concept of an

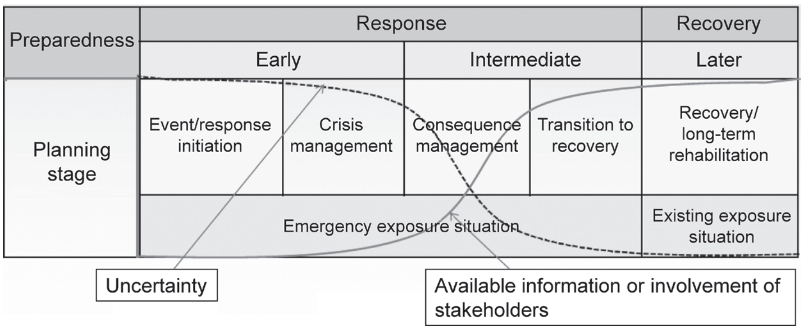

Figure 1 Timeline of emergency management and the emergency phase

existing exposure situation can be applied to the later recovery management. The concepts adopted by the ICRP are explained later in Section IV-5.

2. Emergency Response Goals

In the safety requirements established in GS-R-2, the IAEA has taken a management approach to ensure the substantial achievement of emergency response goals by developing an emergency management system based on the most efficient and effective method. The approach sets forth the following goals for the first step:

(1) to regain control of the situation;
(2) to prevent or mitigate consequence at the scene;
(3) to prevent the occurrence of deterministic health effects in workers and the public;
(4) to provide first aid and manage the treatment of radiation injuries;
(5) to prevent, to the extent practicable, the occurrence of stochastic health effects in the population;
(6) to prevent, to the extent practicable, the occurrence of non-radiological effects on individuals and among the population;
(7) to protect, to the extent practicable, property and the environment; and
(8) to prepare, to the extent practicable, for the resumption of normal social and economic activity.

Next, a response strategy is considered based on the experience of past emergencies and emergency response drills, detailed analysis and understanding of emergency situations, and principles derived from international law as well as principles of justification and optimization of protective actions. Detailed preparedness and response requirements are derived from the strategy.

This approach puts a clear emphasis on the importance of preparedness to ensure an effective response and achieve these goals rather than responding to a de facto situation reactively. An emergency involves various uncertainties, but before such uncertainties can be substantially reduced, decisions on protective actions must be taken based on an analysis of the given situation. For this reason, the IAEA points out the importance of employing a strategy for protective actions that gives due consideration to uncertainties with the aim of ensuring that decisions on protective actions that produce more benefits than harm can be taken when they are most effective.

3. Protective Action Strategy in the Early Phase

Past experience of accidents, such as those that occurred at the TMI and Chernobyl plants, as well as studies on severe accidents and probabilistic safety assessments (PSAs) demonstrate the extreme difficulty involved in assessing the situation resulting from an ongoing accident and predicting the accident’s progression. Even greater uncertainties can complicate estimations of the following: the release and transport of radioactive material inside a facility; the resultant source terms for the environment; the dispersion and deposition of radioactive material in the environment; and the resultant doses. It is virtually impossible to predict sufficiently precise source terms quickly enough to enable decisions to be made on urgent protective actions. Bearing in mind the uncertainties that prevail during an emergency, the IAEA justifies the adoption of a precautionary approach to take urgent protective actions in all directions within a predetermined range whenever a severe condition is detected at a facility in order to prevent any deterministic effects even if the condition does not lead to radiation exposure. The type of protection strategy adopted by the IAEA in the early phase is based mainly on an idea developed by the Nuclear Regulatory Commission (NRC) of the United States. According to the underlying American principle, operators are primarily responsible for any accidents. Because operators are presumably the most knowledgeable about accidents, they are required to issue protective action recommendations for off-site areas. State governments at the subnational level are, of course, ultimately responsible for the judgments and decisions taken with respect to protective actions. The NRC reviews the recommendations of the operators and offers adequate counsel. The protection strategy adopted by the IAEA in the early phase is outlined below along the lines of a paper presented at an international symposium entitled *Emergency management in the early phase* [13].

(1) Aspects of severe accidents at nuclear power plants

[1] Uncertainty about the amount and duration of a radioactive release caused by core damage

In the event of any trouble at a reactor facility, operators try to mitigate the impact of any ensuing accidents by shutting down the reactor to stop a fission reaction, cooling the core to remove any decay heat, and implementing other measures to protect the reactor core. Nonetheless, any failure of a safety system designed to protect a reactor core may lead to cladding damage in several minutes to several hours from fuel overheating (note that the fuel temperature is not evenly distributed and that the rate of temperature increase depends on the availability of cooling systems and the level of the Zircaloy-steam reaction). In addition, the time of the core exposure can only be roughly estimated. Therefore, it is nearly impossible to predict precisely how radionuclides released from a core will change over time and when their release will end.

Operators may be able to predict, or at least detect, extremely severe fuel damage by using direct indicators of impending cladding damage (e.g., a reduced core water level and a temperature increase) and an increase in radiation associated with cladding damage. Only an extremely inaccurate estimate can be made concerning the amount of radioactive material released from a nuclear reactor into the primary containment vessel (PCV).

[2] Uncertainty about environmental releases from damaged primary containment vessels

A severe accident can escalate in a reactor cooling system through various sequences, and it can cause various modes of damage to a PCV. The most likely sequences of an accident and the probabilities of different modes of PCV damage are assessed by conducting PSAs. For instance, the NRC has conducted an extensive study of nuclear power plants in the United States to estimate the probabilities of early PCV damage being caused by factors such as station blackouts or a loss of coolants (NRC, 1990) [14]. They have also studied various modes of PCV damage, including the following: damage caused by high pressure or high temperature; damage caused by a possible direct containment heating of a PCV if a molten core melts through the lower head of a reactor vessel under a high reactor pressure; and damage caused by a failure to close the valve that isolates the interior of the PCV immediately.

Although PSAs do cover such damage, the reality is that few operators can accurately predict whether and when a PCV will suffer damage and how much radioactive material will leak out as a result. There are safety systems that can reduce the release of radionuclides from PCVs, such as sprays, filters, pools, and ice-condensers. However, it is difficult to predict to what extent a release can be reduced under extreme and uncertain conditions. To complicate matters, the safety systems could fail, or a containment bypass could occur, resulting in a radioactive release.

According to the NRC's risk study, PCV damage that occurs in the early phase due to core damage is estimated to release between 1% and 20% of the iodine that has accumulated in the reactor core. This range can be much larger for other major nuclides. This uncertainty is extremely important. Indeed, the release of less than 1% of the iodine may not produce any severe deterministic effects off-site, but the release of 20% within a short period of time may cause deaths if no protective actions are taken.

The typical sequences for accidents that could lead to a massive release are as follows: 1) a system failure or operator error; 2) failure of the safety systems designed to protect the fuel; 3) the core gets uncovered; 4) the fuel heats up and fails; 5) radioactive material is released from the fuel into a PCV or other plant areas; 6) the containment fails or is bypassed resulting in a release to the atmosphere; and 7) actions are taken to mitigate the accident, slow and stop the release, and stabilize the plant. Instruments in the control room can detect events up to the fifth stage of these sequences, but they cannot accurately predict events in the sixth stage that would significantly influence the timing and magnitude of any release. As is the case with PCV damage, most large releases take place in undetectable locations. The control room is probably unable to measure the timing and extent of such a release.

[3] Uncertainty about the impact of an environmental release

Despite recent improvements that have enabled extensive atmospheric dispersion to be predicted much more accurately, predictions in regional or local areas remain uncertain due to limited knowledge of the atmospheric parameters for such ranges. Without any environmental measurements, predicting the radionuclide concentration is extremely difficult given the uncertainty about the rate and location of the release, continuous changes in meteorological parameters, and the initial migration of released material according to the local terrain and weather conditions. Once a release is detected through monitoring, it may be possible to estimate how long it will take before the released material reaches residents in nearby communities. However, it would be too late to make any decisions on the protective actions needed to avoid any severe deterministic effects from a fatal release involving massive exposure.

In most sequences for severe accidents, the exposure pathway that produces the most severe deterministic effects is external exposure from surface deposition. For this reason, the effects depend significantly on the occurrence and scale of precipitation. An assessment of the Chernobyl Accident demonstrated that the distribution of the deposition of radioactive material was extremely ununiform. The concentration could differ by over an order of magnitude between two different locations that were only a few hundred meters apart. It is impossible to predict such variations. In a study conducted with assistance from the European Commission (EC) and the NRC [15)], the various degrees of uncertainty were estimated using the key factors involved in estimating the dose after a nuclear accident. Combined with these environmental uncertainties, even accurately determined source terms would only enable the initial dose estimation to be within a factor of 10 to 100 at best from the actual doses.

(2) Prevention of deterministic effects

An assessment of severe accidents [14)] suggests that severe deterministic effects are produced off-site by either critical fuel damage or PCV damage in the early phase. Effective protective actions in the early phase require a swift response before any exposure occurs. In practice, an emergency support team must be established and organized to carry out the necessary measures, which inevitably leads to some delay. Clearly, alerts based on the plant conditions are vital. If operators report a failure that has been detected by a system employed for protecting a reactor core, they can alert the relevant agencies off-site a few hours before any release.

As mentioned earlier, core damage can be predicted through observable conditions, but it is much harder to foresee PCV damage. Due to the considerable uncertainties involved, it is virtually impossible to estimate the amount of release and doses off-site accurately when decisions need to be made. After the core suffers damage, this degree of uncertainty does not change until the scale of the release is indicated by environmental measurements. Precious time would be lost by delaying decisions or waiting for information that would not improve the quality of decisions anyway. Ensuring the prompt protection of residents crucially requires clear criteria for initiating the necessary activities in response to predicted or actual core damage.

This idea forms the basis for emergency classifications in many countries, and it has been incorporated in GS-R-2 as well. The emergency classifications used in GS-R-2 are in line with the four categories presented in Section IV-4. The classification criteria are specified according to predetermined emergency action levels (EALs), which depend on abnormalities in the condition of the facilities, safety-related matters, the release of radioactive material, environmental measurements, and other observable indicators. The scheme provides the basis for alert requirements and defines the authority and duties of relevant agencies according to the emergency classification. Thus, it enables all relevant agencies to take action swiftly according to the declared emergency category.

(3) Minimization of stochastic and non-radiological effects

Another goal of radiation protection during an emergency response is to reduce any resultant stochastic effects. Protective actions that are intended to reduce the stochastic effects can often produce conflicting effects in relation to public finances, society, the economy, and psychology. Damage caused by a severe accident that poses both radiological and non-radiological effects persists for a long time. The pace of recovery from such an accident depends on various factors, including the need to regain and maintain public trust, signs of the emergence of deterministic effects and an increase in the stochastic effects, the number of people who undergo health surveillance, the public perception of government activities during an emergency, and compliance with international standards.

Based on the experiences from the Chernobyl Accident and other past events, the IAEA recommends the following: (1) restrictions on food intake; (2) distribution of iodine thyroid blocking agents; (3) health surveillance; (4) planning of protective activities; (5) operational intervention levels (OILs); and (6) advice for residents. Space limitations prevent us from going into detail, but further information can be found in Reference Material [13].

(4) Strategy for protective actions

In light of the above, the IAEA has recommended the following approach as a means of substantially reducing the human health effects of severe accidents.

(a) Residents within 3 to 5 km should evacuate or shelter in place before or immediately after any major release. In addition, iodine thyroid blocking agents should be distributed to residents who sought shelter near the site before or immediately after the major release. Decisions should be made based only on the conditions of the site facilities, without waiting for the release.

(b) Before or immediately after the major release, warnings must be issued in all areas located within 300 km or more to avoid any intake of potentially contaminated food.

(c) After a release, monitoring should be swiftly carried out around the evacuated areas to allow people to avoid hot spots left by radioactivity deposition. Decisions on protective actions should be made swiftly by applying predetermined OILs to the monitoring results.

4. Basic Requirements Established in GS-R-2

The IAEA established basic requirements for emergency preparedness and response in GS-R-2 based on the protective action strategy in the early phase. **Figure 2** outlines the procedure to be taken in the planning and response stages of responding to an emergency. These requirements essentially adhere to the US approach to emergency preparedness and response. According to these requirements, the following arrangements should be implemented in the planning stage.

(1) Hazard assessments

Operators assess hazards in each category according to the type and scale of the radiation source and facility. Hazards are classified into categories to ensure that preparedness and response measures can be properly prepared and maintained through a graded approach according to their potential magnitudes and nature. Although this classification is not described in detail, its five categories cover the most hazardous nuclear power plants and various other sources of hazards.

In a hazard assessment, accident sequences leading to an emergency can be considered based on the findings of the safety analysis conducted during the designing of the facilities. To do this, all reasonably foreseeable postulated incidents must be taken into account. A hazard assessment must also identify which facilities and sources require the following actions and how extensively in response to an emergency.

a. Precautionary urgent protective actions to prevent severe deterministic health effects by keeping doses below a certain limit under any circumstances

b. Urgent protective actions to prevent stochastic effects by averting doses in accordance with international standards

c. Restrictions on food intake, measures related to agriculture, and long-term protective actions in accordance with international standards

d. Protection for the workers in accordance with international standards

(2) Setting of criteria for emergency classification

Operators must prepare the relevant criteria for classifying emergencies. The IAEA has adopted four categories for the classification of emergencies: (1) general emergencies, which require urgent protective actions both on-site and off-site; (2) site area emergencies, which require actions on-site and preparations in the vicinity of the site as necessary; (3) facility

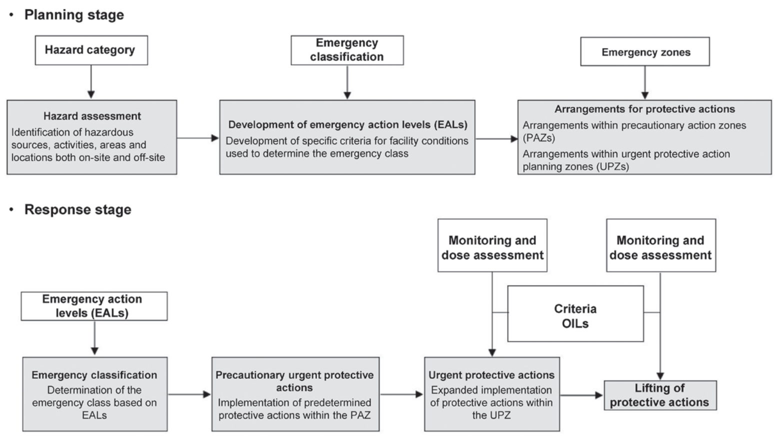

Figure 2 Basic concept of emergency preparedness and response in the IAEA GS-R-2

emergencies, which require the protection of people on-site; and (4) alerts, which are issued at facilities involving an uncertain or significant decrease in the level of protection for the preparation of protective actions. By defining the authority and responsibilities of the relevant agencies in accordance with this classification, all relevant agencies can promptly take action according to the declared emergency category. EALs serve as the criteria for this classification.

(3) Assignment of planning zones for urgent protective actions

Planning zones must be assigned to nuclear power plants and other facilities that are classified as highly hazardous in order to allow the necessary actions to be promptly performed off-site in response to an emergency.

a. Precautionary action zones (PAZs): Necessary arrangements are made according to the facility conditions so that precautionary urgent protective actions can be taken before or immediately after the release of radioactive material to substantially reduce the risk of severe deterministic health effects.

b. Urgent protective action planning zones (UPZs): Necessary arrangements are made so that urgent protective actions can be taken to avert doses in accordance with international standards.

After due preparations have been made for emergencies in the planning stage, actions are taken in response to an actual emergency as shown in Figure 2.

- Emergencies are classified according to EALs
- Urgent protective actions are taken in PAZs as prepared in advance for a general emergency.
- Appropriate urgent protective actions are taken in UPZs while the measurement results from monitoring are compared against OILs.
- Similarly, judgements on the lifting of protective actions are made by comparing the measuring results from monitoring against the relevant criteria.

5. Concept of Radiation Protection in an Emergency

Let us take a brief look at the basic concept of providing radiation protection against emergency exposure situations as recommended by the ICRP in 2007. A more in-depth explanation is available in Serial Lecture, *New ICRP Recommendation—New Radiation Protection Principle and Standards (6); Emergency Exposure Situations* [16]. The recommendations stress the importance of justification and optimization in a protection strategy against emergency exposure situations. A process of optimization based on the reference level is applied to plan protective actions and ensure optimal levels of protection. Such optimization facilitates more comprehensive protection and flexible responses by simultaneously considering all exposure pathways and all relevant protective options. In the planning stage, optimization may also facilitate effective resource allocation by providing a framework of reference on the ways in which protective actions influence one another.

Optimization based on a reference level focuses on the levels of residual doses after the implementation of a protection strategy. This is the main difference in relation to the optimization of a single protective action to avert doses based on the recommendations made by the ICRP in 1990. As shown in **Figure 3**, for example, the conventional optimization of a single protective action is carried out to plan an evacuation if a project dose exceeds an avertable effective dose of 50 mSv, which requires an evacuation unless any other actions are taken.

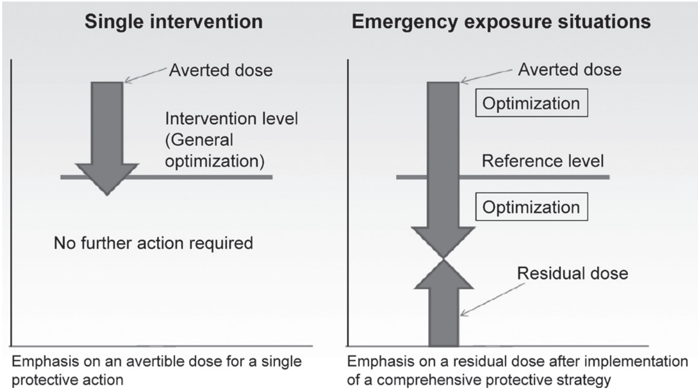

Figure 3 Intervention and optimization under emergency exposure situations

Optimization performed based on a reference level considers all exposure pathways and all relevant protective options. In the planning stage, protective options that reduce residual doses to below the reference level are selected. In response to any emergency exposure situations, the estimated residual dose is assessed against the reference level to consider the effectiveness of a protection strategy and determine whether there is a need to modify specific protective actions or take additional actions. Although it is somewhat more complicated in practice compared to the optimization of a single protective action against emergency exposure situations, such a concept enables optimal protective actions to be planned more flexibly by emphasizing the synergy among all of the actions.

According to the recommendations made by the ICRP in 2007, the reference level for the effective residual dose in relation to a protection strategy under emergency exposure situations should be selected from between 20 and 100 mSv. Any dose beyond 100 mSv increases the likelihood of deterministic effects and carries a significant risk of cancer. The maximum value for a reference level is therefore an acute or annual dose of 100 mSv. The ICRP additionally recommends that all viable protective actions be taken if severe deterministic health effects may exceed the threshold. In the planning stage, the reference level can serve as a criterion for judging the soundness of a protection strategy. In the response stage, the reference level is used as a benchmark for judging the effectiveness of a protection strategy and determining whether there is a need to modify specific protective actions or take additional actions.

6. Criteria for Implementing Protective Actions

As mentioned in Chapter IV, GS-R-2 presents a decision-making procedure for emergency responses. To avoid severe deterministic health effects, precautionary protective actions are taken according to the facility conditions, which are defined by EALs and the emergency classification. Meanwhile, urgent protective actions are taken after the environmental release of radioactive material mainly to reduce the occurrence of stochastic effects. Rather than relying on criteria expressed in terms of doses, judgements are made according to OILs that can be measured in the environment, such as the dose rates and concentration levels of radioactive material in the environment. Examples of these criteria are presented along with the decision-making scheme in General Safety Guide No. GSG-2 [6].

GSG-2 is mainly intended to define consistent generic criteria (GC) that can form the basis for developing EALs and OILs as operational criteria. The guide recommends that GC be first set for precautionary urgent protective actions to prevent any severe deterministic health effects. When this is done, the optimization principle for protective actions must be followed to apply the reference level for the residual dose as presented by the ICRP with the aim of allowing the GC to be set without any inconsistency with the reference levels in the range of 20 and 100 mSv. Once a set of GC has been established, default values must be set with EALs and OILs for initiating protective actions. Under emergency exposure situations, the default values should be adjusted according to the rapidly changing conditions in a pre-determined way.

More specifically, TABLE IV-1 of Schedule IV in GSR Part 3 [5)], which is a revised version of BSS, defines the GC for acute exposure doses for which protective actions or other response actions are expected regardless of the circumstances in order to prevent or minimize any severe deterministic health effects. Similarly, TABLE A-1 in the Annex defines GC for protective actions and other response actions aimed at reducing the risks of stochastic effects. **Tables 1** and **2** present the GC for preventing deterministic health effects and the GC for reducing stochastic effects, respectively. They are expressed in terms of the given organ doses or effective doses.

Further information can be found in the appendices of GSG-2 entitled "Development and examples of EALs for light water reactors" and "Examples of default OILs for deposition, individual contamination, and contamination of food, milk and water."

Table 1 Generic criteria for avoiding severe deterministic effects

Generic criteria	Examples of protective actions and other response actions
Acute external exposure (less than 10 h) Red marrow*1: 1 Gy Fetus: 0.1 Gy Tissue*2: 25 Gy at 0.5 cm Skin*3: 10 Gy to 100 cm^2	If the dose is projected: • Take precautionary urgent protective actions immediately (even under difficult conditions) to keep doses below the general criteria • Provide public information and warnings • Carry out urgent decontamination
Acute internal exposure due to an intake (Δ = 30 d*4) Red marrow: 0.2 Gy for radionuclides with atomic number Z ≥ 90*5 2 Gy for radionuclides with atomic number Z ≤ 89*5 Thyroid: 2 Gy Lung*7: 30 Gy Colon: 20 Gy Fetus*8: 0.1 Gy	If the dose has been received: - Perform immediate medical examinations, consultations, and indicated medical treatment - Carry out contamination control - Carry out immediate decorporation*6 (if applicable) - Carry out registration for longer term medical follow-up - Provide comprehensive psychological counseling

*1: External dose to red bone marrow, lungs, small intestine, gonads, thyroid, and lens of the eye caused by exposure in a uniform field of strongly penetrating radiation.

*2: A dose delivered to 100 cm^2 at a depth of 0.5 cm under the tissue surface due to close contact (e.g., with a radiation source carried in a hand or pocket)

*3: A dose delivered to the 100 cm^2 dermis, the skin structure at a depth of 40 mg/cm^2 (i.e., 0.4 mm) below the surface.

*4: AD (Δ) denotes an absorbed dose delivered over a period of time Δ by an intake (I_{05}) that will result in a health effect in 5% of exposed individuals.

*5: Different criteria are used to take into account differences in the intake thresholds among radionuclides.

*6: General criteria for decorporation are based on projected doses without decorporation.

*7: In this commentary, the term "lung" refers to the alveolar-interstitial (AI) region of the respiratory tract.

*8: An absorbed dose to fetus during utero development.

Table 2 Generic criteria for reducing stochastic effects

Generic criteria		Examples of protective actions and other response actions
Projected dose that exceeds the following generic criteria: Take urgent protective actions and other response actions.		
Thyroid equivalent dose	50 mSv (first 7 days)	Iodine thyroid blocking
Effective dose Fetal equivalent dose	100 mSv (first 7 days) 100 mSv (first 7 days)	Sheltering, evacuation, decontamination, intake restriction on food, milk, and water, contamination control, reassurance of the public
Projected dose that exceeds the following generic criteria: In the early phase of an emergency, take urgent protective actions and other response actions.		
Effective dose Fetal equivalent dose	100 mSv (annual) 100 mSv (entire period of utero development)	Temporary relocation, decontamination, substitution of food, milk, and water, reassurance of the public
Received dose that exceeds the following generic criteria: Take long-term medical actions to detect and effectively treat radiation induced health effects		
Effective dose	100 mSv (in a month)	Health screening of specific radiosensitive organs based on equivalent doses (as a basis for long-term medical follow-up) and counseling
Fetal equivalent dose	100 mSv (entire period of utero development)	Counseling to allow informed decisions to be made in individual circumstances

V. Conclusions

This commentary began with a brief review of the lessons learned from the Fukushima Daiichi NPP Accident with respect to preparedness and response in a nuclear emergency. It then provided an overview of international standards that the NRA referenced in its development of the NRA EPR Guide. The focus of this commentary was GS-R-2, which defines the safety requirements established by the IAEA, along with the underlying basic concept of the protection strategy for an emergency response. As an emergency response involves many organizations, sufficient coordination is required to ensure its effectiveness. The prerequisite is the development of a plan based on the established principles and basic concept of radiation protection and safety as explained in this commentary. As a further step, an arrangement should be reached to clearly divide the various responsibilities among all of the relevant organizations and deliver an integrated and coordinated response under a sufficiently clear agreement. Drills should be conducted so that the arrangements can be constantly modified to ensure an effective response in practice.

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Toward Enhancing Preparedness and Response Arrangement and Capabilities for a Nuclear Emergency (2)

−National and Local Government Activities and Proposal to the Future−

The Japan Atomic Power Company, **Takashi Nitta**

The government of Japan has been carrying out a systemic overhaul of its nuclear emergency management by taking heed of the experience and lessons learned from the accident that occurred at the Fukushima Daiichi Nuclear Power Plant, which is operated by the Tokyo Electric Power Company (TEPCO). A new framework was constructed to implement adequate measures against nuclear emergencies. The specific steps include the following: the establishment of the Nuclear Regulation Authority; a revision of the Basic Disaster Management Plan in line with the Basic Act on Disaster Management; a revision of the Act on Special Measures Concerning Nuclear Emergency Preparedness (Nuclear Emergency Act) as a special act pursuant to the Basic Act on Disaster Management; and the establishment of the Guidelines for Measures against Nuclear Emergencies in accordance with the Nuclear Emergency Act. In keeping with these steps, municipalities located within roughly 30 km of the nuclear power plant are developing their own regional disaster prevention plans (against nuclear emergencies) and evacuation plans.

This commentary summarizes presentations made at a session organized by the Nuclear Safety Division when the Annual Meeting of the Atomic Energy Society of Japan (AESJ) was held in spring 2014.

I. Efforts Made by the National Government

In the first presentation, entitled “Further measures to be taken for managing nuclear emergencies,” [1] Mr. Yasushi Morishita (Director, Emergency Preparedness/Response and Nuclear Security Division, Secretariat of the Nuclear Regulation Authority) addressed the issue of measures taken by the national government. A summary is provided below.

The respective investigation commissions appointed by the Cabinet and the Diet have identified various issues concerning the response by the national government to the accident that occurred at the Fukushima Daiichi Nuclear Power Plant. Examples of these issues include the crisis management framework and the government’s response to the emergency on-site (to

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bring the accident under control) and off-site (to provide radiation protection for residents near the site and assistance to those affected). Bearing these issues in mind, the national government has been carrying out a systemic overhaul of its nuclear emergency management, which also covered the framework for taking necessary measures and crisis management organizations. A new framework was constructed to allow adequate measures to be taken when responding to a nuclear emergency. The specific steps include the following: the establishment of the Nuclear Regulation Authority (NRA)[2)]; a revision of the nuclear emergency management part of the Basic Disaster Management Plan in line with the Basic Act on Disaster Management[3)]; a revision of the Act on Special Measures Concerning Nuclear Emergency Preparedness (Nuclear Emergency Act) as a special act pursuant to the Basic Act on Disaster Management[4)]; and the establishment of the Guidelines for Measures against Nuclear Emergencies in accordance with the Nuclear Emergency Act[5)]. In keeping with ongoing revisions to these guidelines, nuclear emergency management is being further pursued and fostered by, for instance, supporting relevant efforts made by the host communities of nuclear power plants.

1. Issues Identified in Relation to the Response to the Accident at TEPCO's Fukushima Daiichi Nuclear Power Plant

The respective investigation commissions appointed by the Cabinet and the Diet have identified various issues concerning the response by the national government to the accident that occurred at the Fukushima Daiichi Nuclear Power Plant[6, 7)], which is operated by the Tokyo Electric Power Company (TEPCO).

(1) Crisis management framework for emergencies

The entangled communication and decision-making that took place at the central level (Prime Minister's Office and the Nuclear and Industrial Safety Agency (NISA)) hindered local command and coordination. Furthermore, the relevant agencies did not share enough information. These problems were compounded by the dysfunctional Emergency Response Support System (ERSS), the System for Prediction of Environmental Emergency Dose Information (SPEEDI), and the off-site centers.

(2) On-site response (to bring an accident under control on-site)

Effective use of communication channels was hampered partly by the dysfunctional off-site centers. An adequate scheme was not in place to deal with the accident and not enough professionals with adequate expertise were available to provide the necessary advice and guide the responsible personnel and relevant agencies through their response to the emergency. The commissions also pointed out that not enough drills had been conducted in anticipation of severe accidents.

(3) Off-site response (radiation protection for residents near the site and assistance to those affected)

Numerous updates to the evacuation zones forced many residents to evacuate multiple times and resulted in extended affected areas. The inadequate level of preparedness in relation to protecting residents and providing support to those affected became clear when hospitals and care homes for the elderly could not secure a means of evacuation or find safe havens. Another issue to be identified was the protracted ex-post measures that were conducted to address concerns among residents over environmental contamination and the radiological impact.

2. Systemic Overhaul of Nuclear Emergency Management Based on Critical Comments

Bearing in mind the critical comments presented in the previous section, the national government has sought to perform a systemic overhaul of nuclear emergency management in the following manner.

(1) Institutional framework for nuclear emergency management

The national government has revised the nuclear emergency management part of the Basic Disaster Management Plan, which has been developed in line with the Basic Act on Disaster Management. In this manner, they have sought to reinforce the national crisis management framework, prepare to protect residents and support those affected, and build up the necessary infrastructure. In accordance with the Nuclear Emergency Act, the NRA has established the Guidelines for Measures against Nuclear Emergencies to define specialized and technical matters related to nuclear emergency management. Action plans to be adopted by the respective stakeholders during a nuclear emergency have been developed in line with the revision of the nuclear emergency management part of the Basic Disaster Management Plan as well as the establishment and revision of the Guidelines for Measures against Nuclear Emergencies. The national government has revised their Nuclear Emergency Management Manual and the Disaster Management Operation Plan. Similarly, municipalities have revised their regional disaster prevention plans and power utilities have revised their disaster management operation plans.

(2) Overhaul of crisis management organizations

The Nuclear Emergency Preparedness Commission, which is chaired by the prime minister, has been permanently established to implement measures according to the Guidelines for Measures against Nuclear Emergencies. In this manner, a framework was laid out for the entire government to implement necessary measures on a regular basis in anticipation of nuclear emergencies. During an emergency, a Nuclear Emergency Response Headquarters is to be established under the leadership of the prime minister to take charge of the overall coordination of stopgap and ex-post measures taken in response to a nuclear emergency. Under normal circumstances, the NRA develops and revises safety regulations and the Nuclear Emergency Response Guidelines. During an emergency, however, the NRA guides and supervises the activities conducted by the operators to bring an accident at a nuclear facility under control.

(3) Modifications to nuclear emergency management in the Basic Disaster Management Plan

– Reinforcement of the government's capacity to respond to nuclear emergencies

The government has decided to undertake the following measures: enhance the capacity of the Prime Minister's Office in relation to making decisions and sharing information; clarify the roles necessary to conduct the on-site and off-site response to an emergency; conduct practical drills to simulate complex disasters and severe accidents; and ensure mutual collaboration among the multiple headquarters established to respond to a complex disaster.

– On-site response (to bring an accident under control on-site)

Power utilities are to reinforce their capacity to manage nuclear emergencies, including in terms of emergency response stations, logistic support bases, and nuclear emergency rescue teams (permanent teams to centrally control and operate the necessary equipment for stopgap measures under a high-dose environment). Attempts are to be made to improve coordination and develop a more robust capacity, including for operational units, by conducting drills and other regular measures under ordinary circumstances.

– Off-site response (radiation protection for residents near the site and assistance to those affected)

Attempts are to be made to enhance protection for residents by planning an evacuation procedure in advance for each area, clarifying the procedure for announcing the results of estimates produced by SPEEDI, and putting in place a monitoring system for the event of an emergency. Closer support is to be provided for those affected by a nuclear emergency by established teams tasked with supporting their livelihoods by finding host communities for evacuees and helping them temporarily return to their home communities.

– Better infrastructure and equipment for managing disasters

Better infrastructure and equipment are to be put in place, including the following: networks that allow video-conferencing and other modes of communication among the Prime Minister's Office, the NRA Secretariat, nuclear power utilities, and municipalities; satellite connections and multiple communication routes to build a reliable network that allows uninterrupted communication during complex disasters; reliable emergency power supplies; and more robust equipment and infrastructure at off-site centers.

– Ex-post measures

The government is to take responsibility for health counseling, decontamination, and other ex-post measures, even after a state of emergency has been lifted.

(4) Establishment and revision of the Guidelines for Measures against Nuclear Emergencies

– Classification of emergencies

Emergencies were classified into the following three categories according to the conditions of the nuclear facilities: alerts, site-area emergencies, and general emergencies. Protection of residents, the performance of emergency monitoring and other such necessary measures were prescribed according to this classification.

– Introduction of emergency action levels

As criteria for classifying the abovementioned emergencies, emergency action levels (EALs) were assigned according to the condition of the equipment at nuclear facilities in the respective levels of defense in depth as well as their functions in relation to containing radioactive materials. Evacuation and sheltering in place are to be conducted according to EALs.

– Introduction of operational intervention levels

Operational intervention levels (OILs) were assigned based on air dose rates to prescribe the evacuation planning, temporary relocation, restrictions on food and water intake, and other such necessary measures accordingly.

– Priority zones for additional disaster management measures

In light of mistakes made during evacuations, the guidelines were revised to pre-assign precautionary action zones (PAZs) and urgent protection action planning zones (UPZs) in preparation for evacuations and to implement the necessary protective measures, such as evacuation, sheltering in place, and temporary relocation, in accordance with EALs and OILs.

– Overhaul of the emergency monitoring system

According to the revised version of these guidelines, the national government, local governments, nuclear utilities, and other stakeholders must work together to establish an emergency monitoring center. The national government must take the lead in emergency monitoring and ensure that the relevant organizations can function smoothly even during an emergency. Under ordinary circumstances, the relevant organizations are expected to deepen their intercommunication by holding liaison meetings and joint drills.

– Preparations for the prophylactic administration of iodine thyroid blocking agents

Necessary measures have been prepared for the prior distribution and prophylactic administration of iodine thyroid blocking agents in the event of a nuclear emergency.

(5) Revision of regional disaster prevention plans

Regional disaster prevention plans are basic documents that municipalities use in responding to a nuclear emergency. They compile the key data required to manage a disaster, such as information on shelters, medical institutions dealing with radiation exposure, evacuation roads, monitoring stations, population distribution, equipment and materials, and the deployment of iodine thyroid blocking agents.

(6) Revision of disaster management operation plans drawn up by power utilities

Disaster management operation plans drawn up by power utilities define matters such as how they should organize themselves to manage a nuclear emergency, what equipment and materials they should use, and how they should conduct drills and implement stopgap measures. The content of these plans has been significantly expanded as described below. In addition, the scope of necessary consultation for the development or modification of disaster management operation plans was expanded to include the governors of prefectures that have regional disaster prevention plans (for nuclear emergency management) covering all or part of an area within 30 km of a nuclear power plant.

- Installation and operation of equipment for transmitting information from a nuclear site, emergency response stations at the nuclear site, offsite centers, and the Nuclear Power Facility Immediate Response Center
- Installation and operation of emergency communication equipment and video-conferencing systems at the respective bases
- Formation and deployment of nuclear emergency rescue teams (units for operating and managing remote-controlled devices and other equipment)
- Installation of emergency power supplies for the respective bases, centers, and systems and maintenance of their functions during a natural disaster
- Matters related to evaluation of drills conducted by nuclear power utilities
- Establishment of an information and communications network for connecting the Prime Minister's Office, the NRA Secretariat, and other relevant stakeholders and provision of a reliable connection via video-conferencing systems at emergency response stations

3. Initial Response by the Government

The government must take the following actions in its initial response as required according to the particular event and its escalation.

(1) An initial response by the government is required for the following three types of events.

[1] Alerts

- An earthquake with an intensity of 6-lower or greater on the Japanese seismic intensity scale in a prefecture that hosts a nuclear power plant
- A major tsunami alert issued in a prefecture that hosts a nuclear power plant
- A severe failure or other issue at a nuclear reactor facility (e.g., leakage of cooling water from a reactor or leakage of steam from a ruptured pipe)

[2] Events prescribed in Article 10 of the Nuclear Emergency Act (site area emergencies)

- Leakage of reactor coolant
- Plant blackout for more than five minutes
- Complete loss of the function for cooling a reactor during its shutdown

[3] Events prescribed in Article 15 of the Nuclear Emergency Act (general emergencies)

- Complete loss of emergency AC power supplies for more than five minutes
- Complete loss of the function for shutting down a reactor when an emergency shutdown

is necessary
- An air dose rate of 5 μSv/h for more than 10 minutes at the site border

(2) If a power utility reports any of the events prescribed in Article 10 of the Nuclear Emergency Act to the NRA, the following steps are taken to establish a Nuclear Emergency Response Headquarters:

[1] The Minister of the Environment, the NRA Chairman, and the Secretary-General of the NRA Secretariat report the situation to the prime minister.

[2] If an event prescribed in Article 15 of the Nuclear Emergency Act escalates, the NRA Chairman, the Minister of the Environment, and the Secretary-General of the NRA Secretariat collectively submit proposals to the prime minister for the declaration of a state of emergency and an evacuation order.

[3] The prime minister declares a nuclear emergency, after which cabinet approval is obtained for the establishment of a Nuclear Emergency Response Headquarters headed by the prime minister (who is referred to as the Chief of the Government Nuclear Emergency Response Headquarters).

(3) Once a nuclear emergency has been declared and a Nuclear Emergency Response Headquarters has been established, the following steps are taken.

[1] The Nuclear Emergency Response Headquarters is convened to establish a policy for implementing stopgap measures, including the designation of evacuation zones and distribution of iodine thyroid blocking agents.

[2] The Chief of the Government Nuclear Emergency Response Headquarters orders the relevant ministries, agencies, and municipalities to evacuate or shelter residents, prophylactically administer iodine thyroid blocking agents, restrict food intake, and protect residents from radiation (offsite measures).

[3] The Chief of the Government Nuclear Emergency Response Headquarters orders the relevant ministries, agencies, and organizations to implement stopgap measures (onsite measures) to bring the accident at the plant under control according to the needs of the power utility.

After the presentation, the following questions were raised and answered.

Q: In relation to the presented zoning rules for nuclear facilities, how are PAZs and UPZs designated for the Fukushima Daiichi and Daini Nuclear Power Stations?

A: Because of the presence of Units 5 and 6, the zoning rule applied to the Fukushima Daiichi Nuclear Power Station is the same as that for other facilities. Similarly, that for the Fukushima Daini Nuclear Power Station is the same as that for other facilities; Its PAZ has a range of 5 km and its UPZ has a range of 30 km. The zoning rule for the Fukushima Daiichi Nuclear Power Station is currently being re-examined.

Q: Compared to the reviews conducted by the NRC in the United States, Japan seems to adopt a different approach with respect to the reviewing of disaster prevention plans. How is the ongoing review aimed at resuming the operation of nuclear power plants in Japan going?

A: In the United States, evacuation plans are reviewed by the NRC before the construction of a nuclear reactor is approved. Under Japanese law, though, municipalities must develop their own plans for preventing disasters and evacuating residents. The national government helps municipalities located near the nuclear power plants to develop their own plans and keeps track of their progress. France takes the same approach as Japan.

Q: According to the presentation, the Fukushima Nuclear Accident prompted a systemic overhaul of nuclear emergency management. However, it is not very clear what has changed since the accident. It seems that the system is being streamlined, but will it be able to handle a disruption to any of the interconnections?

A: The system has fundamentally not changed since the accident. However, the division of roles and responsibilities has been clarified. For instance, utilities became primarily responsible for the responses taken on-site. The Prime Minister's Office supports efforts on the ground and the NRA provides technical advice to the prime minister. Drills are considered crucial and they will be conducted to make further improvements.

II. Efforts Made by Municipalities

In the next presentation, entitled "Evacuation measures taken in Shimane Prefecture and challenges ahead," [8)] Mr. Noriaki Shimada, Director of the Office for Evacuation, Nuclear Safety Division, Disaster Management Department, Shimane Prefecture, explained how municipalities are undertaking their respective efforts. A summary is provided below.

In Shimane Prefecture, the Fukushima Daiichi Nuclear Accident prompted local efforts to reinforce the organizations that handle nuclear-related operations and to prevent nuclear emergencies. In the process of developing an extensive evacuation plan, the prefecture has addressed various practical needs. These needs include the following: deployment of necessary vehicles; medical assistance for those who require it; recruitment of necessary caregivers; securement of necessary supplies, equipment, and materials for evacuation and shelters; provision of secondary shelters for a prolonged evacuation; preparation of a screening system that can attend to large numbers of evacuees; and a specific method for determining the extent of the evacuation zones based on the results of emergency monitoring. The prefecture is also addressing challenges that emerged during the Fukushima Daiichi Nuclear Accident, such as the issue of how iodine thyroid blocking agents should be distributed.

1. How Shimane Prefecture has Organized and Carried Out Their Efforts Since the Fukushima Daiichi Nuclear Accident

The Shimane Nuclear Power Plant is the only plant in Japan to be located in a prefectural capital (Matsue). There are six municipalities within 30 km of the plant: Matsue, Izumo, Yasugi, Unnan, Yonago, and Sakaiminato. As of December 2012, the first four cities in the prefecture have a total population of roughly 398,000.

(1) Organizations established by the prefectural government

Prior to the Fukushima Daiichi Nuclear Accident, nuclear-related assignments in Shimane Prefecture used to be handled by the Nuclear Safety Measures Office, which was part of the Firefighting and Disaster Management Division under the General Affairs Department of the prefectural government. Since the accident, its organizational capacity has been reinforced. In August 2011, the Nuclear Safety Measures Division was established. In the following April, the Nuclear Emergency Management Group, the Nuclear Safety Measures Group, the Evacuation Measures Office, and the Nuclear Environment Center were established within this division. The division was rearranged into the Disaster Management Department in April 2013, with the Deputy Director-General assigned to take charge of nuclear safety.

(2) Efforts made to date

In addition to the reinforcement of the organizational capacity, the following efforts have been made.

– May 2011

The Nuclear Emergency Management Liaison Committee was jointly established by the prefectural governments of Tottori and Shimane along with the six cities located within 30 km of the nuclear power plant. The committee decided to sort out the various challenges and coordinate the necessary actions while bearing in mind the experience of the nuclear emergency that occurred in Fukushima.

– September 2011

Urgent priorities were compiled in an interim report. A summary of these priorities is provided below.

[1] Establish a communication system, multiplex the communication devices, and build up the capacity for taking the initial response

[2] Build up a system for evacuating residents in general

[3] Build up a system for evacuating persons who require special assistance during a disaster

[4] Install additional measurement devices and expand the capacity for conducting emergency monitoring

– October 2011

At a meeting, governors from the Chugoku region were requested to cooperate in hosting evacuees across extensive areas.

– November 2012

An extensive evacuation was planned in Shimane Prefecture according to the following basic policy.

[1] Build up capacity so that information can be reliably shared with residents and those involved in disaster management. Clarify in advance the locations and routes to shelters.

[2] Try to complete evacuations before a massive release of radioactive materials by assuming phased evacuation orders.

[3] Ensure that those who need special assistance during a disaster (including those at home, those in welfare facilities, and patients in hospital) can be evacuated safely and swiftly.

2. Overview of the plan for an extensive evacuation from Shimane Prefecture and challenges associated with the evacuation, etc.

The destinations for an evacuation from the four cities of Shimane Prefecture were distributed radially within Shimane Prefecture, Hiroshima Prefecture, and Okayama Prefecture. The evacuation routes to reach them were carefully arranged to ensure that they would not cross each other. Backup shelters were also arranged inside Tottori Prefecture. An evacuation of residents is normally carried out by having them walk from their homes to a provisional assembly point, move to a transit point by bus (or go directly to the transit point from their home by car), and then travel to the appropriate shelters on foot, by bus, or by other means. Meanwhile, those who need special assistance are evacuated from their homes or welfare facilities to temporary welfare shelters for an extensive evacuation. Hospitalized patients are evacuated directly to other hospitals. Here, the temporary welfare shelters for an extensive evacuation serve as the primary shelters for those in need of special assistance during an emergency. Compared to shelters in the same areas for residents in general, these shelters offer a better living environment as they have air conditioning, accessible restrooms, and other amenities to facilitate nursing care. Those who need special assistance during a disaster require adequate preparations to be made at an early stage to ensure their swift evacuation and reduce the risks that they face. Until preparations for an evacuation have been made, they need to be sheltered in place.

(1) Tasks associated with evacuation of residents

An evacuation of general residents requires the following: [1] arrangements for the necessary means of transport and drivers and [2] arrangements for the necessary supplies at shelters. Consultations are also underway with bus companies.

The evacuation of those who need special assistance requires the following: [1] arrangements for secondary shelters equipped with facilities that offer welfare support; [2] arrangements for hospitals capable of attending to patients who cannot be easily accommodated at their primary destinations; [3] arrangements for medical and nursing professionals who can provide the necessary support while patients are being transported and after they have arrived at their shelters; and [4] arrangements for the necessary means of transport, equipment, and materials according to the conditions of those needing assistance.

(2) Tasks associated with contamination screening

Issues associated with contamination screening include the following: [1] how screening sites should be selected and [2] how screenings should be conducted for large numbers of evacuees and their vehicles.

(3) Tasks associated with evacuation orders

[1] Evacuation before a release of radioactive materials

According to the existing plan, specified persons must be evacuated in the event of a site area emergency at a nuclear power plant. In a general emergency, residents in the PAZ must be evacuated, while residents inside the UPZ must be sheltered in place. Depending on the condition of the power plant, residents inside the UPZ may have to be evacuated in stages. An important task here is to clarify how evacuation orders should be issued and to what extent.

[2] Evacuation after a release of radioactive materials

According to the existing plan and the results of emergency monitoring, an evacuation must be carried out by identifying target areas within a few hours for an OIL of 1 (500 μSv/h) or a temporary relocation must be organized within a week after identifying target areas within one day for an OIL of 2 (20 μSv/h). Given this, it is necessary to specify a method for determining the extent of the area to be evacuated.

(4) Tasks associated with the emergency monitoring system

In addition to 35 posts for regular monitoring, 18 additional posts have been set up for the initial response to an emergency. Depending on how an accident unfolds, 35 more monitoring posts can be added. The issue here is how densely measurements of the radiation dose must be conducted to determine the extent of the area to be evacuated.

(5) Tasks associated with the medical system for urgently attending to radiation exposure

Before the Fukushima Accident, two hospitals were assigned to offer initial care to those exposed to radiation and one hospital was assigned to offer secondary care. Later, the numbers were increased to 14 and 2, respectively. Hospitals are trying to [1] train medical personnel so that they can attend to persons exposed to radiation and [2] develop internal manuals. Unfortunately, not enough personnel have been trained due to limited training opportunities.

(6) Tasks associated with the distribution of iodine thyroid blocking agents

According to the plan, iodine thyroid blocking agents should be distributed to each household in the PAZ. Arrangements have been made to enable them to be administered outside the PAZ in coordination with an evacuation. Their prior distribution is also possible if local governments need to do so in certain areas.

The tasks that need to be addressed going forward are as follows: [1] determination of the scope and intended targets for prior distribution; [2] arrangements for engaging doctors and pharmacists in the distribution; [3] determination of the distribution method to be used at medical institutions; and [4] proper management after the distribution. The prefectural government of Shimane has established a committee for the distribution and administration of iodine thyroid blocking agents to discuss a specific distribution policy.

After the presentation, the following question was raised and answered.

Q: Do evacuation plans and measures take into account the distribution of released radioactivity that was announced in October 2012 by what was then NISA?

A: No. In the planning phase, the distribution is to be arranged for everyone within a 30-km range based on the assumption of maximum exposure.

III. Conclusions

In 2012, the Nuclear Safety Division offered many recommendations during eight rounds of seminars on the Fukushima Daiichi Nuclear Accident [9]. They identified the need to clarify the responsibilities involved in implementing emergency protective measures and conducting emergency management according to the principles of international standards and in chronological order. They also stressed the importance of a tiered chain of command and division of roles, as well as information sharing with the public based on the collected information and judgments made by experts for the appropriate issuing of instructions and alerts for the public.

The AESJ Investigation Committee on the Accident at the Fukushima Daiichi Nuclear Power Plant has also offered recommendations on reinforcing nuclear emergency management in Section (3) “Building up emergency preparedness and response capabilities” of Chapter 8 “Root causes of the accident and recommendations” in its final report [10].

These recommendations are outlined in the appendix.

Nuclear emergency management is pursued in relation to Level 5 defense in depth as a last bastion to protect the public from health damage caused by exposure to radiation. To enhance its effectiveness, the national government would need to provide further support for the efforts being made by the municipalities, such as the development of their evacuation plans. The Division intends to monitor how the relevant organizations incorporate the recommendations offered at the seminars in their efforts to manage nuclear emergencies.

–Appendix–

Building up emergency preparedness and response capabilities
(Excerpt from the final report by the AESJ Investigation Committee)

The emergency response to the Fukushima Daiichi Nuclear Accident was complicated by a misguided initial response, poor coordination among the relevant agencies, an unclear decision-making scheme, and other such problems. Discussions on the response were overly focused on how the tools should be used effectively and how the outcomes were announced.

Among the five levels of defense in depth according to the IAEA, disaster management plans stand as the last bastion for Level 5. Accordingly, the AESJ Investigation Committee analyzed various challenges associated with emergency management and operations, while focusing on how residents should be protected from radiation and how the response targets should be achieved. During this process, the challenges were clarified in relation to urgent protective actions as well as the responsibilities and roles of the power utilities and the national and local governments.

Emergency preparedness and response capabilities must be built up to protect against nuclear emergencies being compounded with earthquakes and other non-nuclear disasters by expecting the worst scenarios. The power utilities must consider all conceivable emergencies at their facilities according to assessments of the target events and seek to minimize radiation risks reliably in reasonably predictable events. Capabilities must be built up regularly so that the predetermined procedure can be taken in any crisis management phase and flexible responses can be taken to handle anything not envisaged by the procedure.

To this end, the committee recommends the improvements described below. The responsibilities and roles of the relevant agencies should be re-examined both on the ground and at the local, national, and international levels. Drills should be conducted so that inter-agency coordination can be continuously modified to ensure effectiveness in responding to emergencies.

- A scheme should be established to allow power utilities and local governments to coordinate their urgent protective actions in the initial phase of crisis management under conditions of great uncertainty when less information is available. They should be able to do so before any radioactive materials are released into the environment by carrying out a predetermined procedure according to the facility conditions in comparison with the preassigned criteria.
- Stakeholders, including the power utilities and the national and local governments, should discuss, decide, and document how their on-site and off-site roles and responsibilities will be divided during an emergency. In principle, the response should be led by the power utility on-site and the local government off-site. The national government should provide the necessary support.
- A detailed policy covering various procedures and urgent actions for crisis management should be clarified in advance by considering the options available through exercises and so forth.
- The method to be used in handling data from SPEEDI and other analyses of the dispersion of radioactive materials should be clarified while recognizing their limited application in, for instance, the initial evacuation.
- The protective actions conducted by local governments and the protection of residents led by the police, fire departments, Self-Defense Forces, and the national government should be integrated under a common platform with reference to examples from other countries, bearing in mind that such activities are almost comparable to the measures employed in managing ordinary disasters.
- The principle of radiation protection and adequate knowledge of the impact of radiation exposure must be instilled among all personnel responsible for measures against radioactivity as a unique challenge posed by nuclear emergencies. Their capacity to handle the necessary tasks should also be built up.

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Commentary

Reconsidering of Risk Communication

−Reconstruction of Nuclear Risk Communication−

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This commentary looks at issues and challenges that were encountered in relation to nuclear risk communication in the aftermath of the Fukushima Daiichi Nuclear Accident. Conventional practices are critically examined to consider how risk communication in the nuclear sector should be reconstructed, and what governments and experts should do to regain the lost public trust.

I. Introduction

The Fukushima Daiichi Nuclear Accident (hereinafter referred to as the "Fukushima Accident") led to the emergence of radiation and radioactivity risks associated with nuclear power. These risks are causing social problems related to the health effects of exposure to low-dose radiation as well as the management and isolation of radioactive waste. They have also given rise to the need for nuclear safety with regard to earthquakes, tsunamis, and other external events as well as the fundamental roles of nuclear itself. Together with the government's Investigation Committee on the Accident at the Fukushima Nuclear Power Plant of Tokyo Electric Power Company, many experts stressed the importance of risk communication. Accordingly, members of Atomic Energy Society of Japan and many other stakeholders began to engage in nuclear risk communication. However, during the three and half years since the Fukushima Accident, nuclear risk communication has not proven effective in practice. This commentary clarifies the issues and challenges encountered in relation to conventional nuclear risk communication. In this discussion, recommendations are also made on how risk communication in the nuclear sector should be reshaped going forward.

II. Characteristics of Nuclear Risk Communication

Nuclear risks are posed by radioactivity and radiation, neither of which can be sensed by humans in any way. For this characteristics, they are regarded as something completely different from the risks posed by other technologies. For example, genetically modified

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organisms, space development, artifacts carry potential risks. The Fukushima Accident has now alerted many Japanese people to the apparent risks that radiation poses to the environment and human life [1].

The conventional method of nuclear risk communication was developed with the aim of promoting public understanding of nuclear and gaining public acceptance in ordinary times based on the fundamental assumption that nuclear safe was assured, without postulating a major disaster. This risk communication method encouraged the adoption of a paternalistic approach in which experts would provide explanations to convince people according to their own agenda.

Furthermore, the series of nuclear accidents and scandals that have occurred since 1995 has caused the public to develop a sense of distrust toward such risk communication on the basis that it is driven by the collective interests of the pro-nuclear lobby, which is sometimes referred to as the "nuclear village."

According to popular perception, politicians cannot be trusted. They often say things like, "A clear explanation should be provided to the public to gain their understanding" all for the sake of "their safety and peace of mind." However, the phrase "gain their understanding" tends to be regarded as an attempt to convince people. It is common knowledge in the field of risk communication that the use of this phrase in this type of context actually arouses mistrust, contrary to the intention of gaining trust.

Another characteristic of nuclear risk communication is its focus on external communication with the public. For this reason, no strategic measures have been taken by organizations through any process, including their governance and internal communication, with due consideration given to risk governance and social responsibilities. These organizational issues and challenges are discussed in Chapter IV.

III. Issues and Challenges Related to Nuclear Risk Communication

1. Concept of Risk

Before discussing issues and challenges associated with nuclear risk communication, let us look at the concept of risk.

Scientists and engineers commonly define the term "risk" as being the product of an event's probability and its impact (i.e., the magnitude of an event's consequence).

Similarly, the Nuclear Regulatory Commission (NRC) in the United States defines "risk" as the product of an event's probability and its consequences [2]. However, ISO 31000:2009, an international standard for risk management, defines "risk" as the "effect of uncertainty on objectives" [3]. Rather than it being defined by probability, such a risk clearly takes into consideration both desirable effects and undesirable effects. In economics, risk can represent both losses and gains. If this approach is adopted with respect to radiation, risk involves a trade-off between hazards and benefits as shown in **Figure 1**. Meanwhile, Peter Sandman, a sociologist who specializes in risk, has developed the following formula: "Risk = Hazard + Outrage" [4]. Various definitions and concepts of risk are applied in different fields. This means that, before using the term "risk," people from different backgrounds must first agree on a definition.

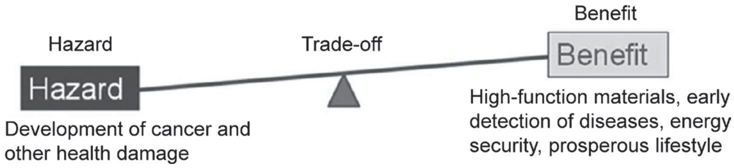


Figure 1 Trade-off of risks associated with radiation

2. Issues Associated with Nuclear Risk Communication

After the Fukushima Accident, the government of Japan developed a policy package for radiation risk communication to enable those affected by the accident to return home in accordance with the action plan for addressing health concerns among such people (decision issued on May 31, 2012, by the coordination committee tasked with addressing health concerns among people affected by the nuclear accident)[5)]. Such efforts are to be undertaken jointly by the Reconstruction Agency, the Ministry of the Environment, the Cabinet Office, the Food Safety Commission, the Consumer Affairs Agency, the Ministry of Foreign Affairs, the Ministry of Education, Culture, Sports, Science and Technology (MEXT), the Ministry of Health, Labour and Welfare, the Ministry of Agriculture, Forestry and Fisheries, the Ministry of Economy, Trade and Industry, and the Secretariat of the Nuclear Regulation Authority. This package also encourages risk communication by, for example, preparing national documents on the health effects of exposure to radiation, conducting training for professionals involved in the healthcare, welfare, and education sectors, and developing participatory programs.

In Fukushima Prefecture, radiological education is conducted in elementary and junior high schools using instructional materials[6)] on radiation prepared by the prefectural board of education and a supplementary reader[7)] on radiation prepared by MEXT for elementary and junior high school education. Risk communication is also carried out independently by the Japan Health Physics Society[8)], the Japanese Radiation Research Society[9)], and many other learned societies and associations as well as educational and research institutes. These numerous efforts to carry out risk communication in practice deserve praise, but are the public actually aware of the outcomes of these efforts?

The overall issues associated with nuclear risk communication are examined by analyzing some of these risk communication practices concerning the health effects of exposure to radiation.

(1) Attention to context

After the Fukushima Accident, the media shared a message from experts calling for "a suitable degree of fear based on a proper understanding of radiation." This message was intended to raise awareness among the public and encourage them to gain an accurate understanding of the health effects of exposure to radiation. Essentially, the message implied that it is important to gain an accurate understanding of radiation risks. However, people with little interest or understanding of radiation tended to skip over the actual implications and interpret the message out of context to mean, "Let's fear radiation." Despite its coincidentally similar wording, the message was probably not inspired by *Two Minor Eruptions*[10)], an essay written by Torahiko Terada on the eruptions of Mount Asama. In his essay, Terada refers to "a suitable fear" to point out that "it is easy for people to fear something too little or too much, but it is difficult for them to develop an appropriate amount of fear." This message was misinterpreted in contradiction to this line.

The same problem was experienced with a press release issued following the Fukushima

Accident when the chief cabinet secretary announced that there would be "no immediate health damage." Mindful of public concerns, the secretary was trying to reassure the public that there would be no health damage. Instead, public anxiety was fueled by the misinterpretation that "the health damage would manifest itself later."

These examples demonstrate that choosing the right expressions in risk communication can be tricky. Depending on the context, especially if only a limited amount of information is available, the expressions used can even be interpreted in ways that are completely opposite to their intended meaning. Risk communication should not be guided by the logic of an information provider. All expressions must be carefully examined to consider how they might be perceived by the intended recipients.

(2) Attention to the amount of information

The national document entitled *Basic Information on Radiation Risks* [11] contains a vast amount of information that is divided into 15 sections over 36 pages. In the introduction, the document defines itself as a document that is intended to provide a clear and accurate explanation of the basics of radiation risk, including the use of terms. Admittedly, the document is accurate thanks to the oversight provided by experts, but it is hardly clear for readers.

For instance, although the term "risk" appears 16 times in the body text and figures, it is only explained in a footnote written in a small font on p. 15 that states, "A risk is the scale of probability of the manifestation of a harmful effect. It is not simply an antonym of 'safety' or a synonym of 'danger.'" The document also states that, "Risk communication in practice requires the creation of documents that conscientiously address matters of interest to the intended targets." However, that leaves us with the question of who is supposed to convert this difficult, hard-to-understand information into fine-tuned explanations.

The author has been carrying out risk communication regarding low-dose radiation for the citizens of Tsuruga. This experience has taught him that an excessive amount of information makes it difficult for the recipients to get a clear view of the overall picture and pick out answers to important questions such as "Are we safe?" and "How will our children and future generations be affected?"

In nuclear risk communication, the amount of information to be provided to stakeholders must be adjusted according to their levels of understanding to make sure that the information they require is clarified.

(3) Intercomparison of risks

People often compare radiological risks with other risks, such as the risks of cancer development as published by the National Cancer Center [12].

It is easy to compare the risks of cancer development associated with smoking, drinking, lack of exercise, insufficient intake of vegetables, and low-dose radiation. However, the implications of such a simple comparison need to be carefully examined. Many smokers and drinkers are aware of the health risks that their choices entail. Many other people take care to avoid smoking, drinking, lack of exercise, and insufficient intake of vegetables. These people were not exposed to low-dose radiation by choice, though. In this sense, a comparison with other risks is meaningless. In fact, such a comparison could even come across as an attempt to trivialize the risks of radiation-induced cancer development.

Western practitioners of risk communication have learned from their own experience that a simplistic comparison of radiological risks and other risks can undermine public trust in them [2]. Consequently, they refrain from conducting thoughtless comparisons of risks. Instead, they make careful comparisons only for people who care about the health of others. Despite this, why are thoughtless comparisons of risks still being conducted in Japan?

One underlying cause is the false assumption made by experts that they can expect the public to make rational judgements after comparing the levels of risks for them. Unfortunately, it must be kept firmly in mind that people do not make rational judgements when it comes to risks. People may cease to trust anything a person says if they have previously resorted to thoughtless comparisons of risks.

3. Challenges Associated with Nuclear Risk Communication

Risk communication requires a methodology with theoretical foundation in liberal arts and social sciences. The methodology cannot be discussed in isolation from the practice. There are certainly tried and true procedures. Nonetheless, in practice, careful preparation and flexible response must be made in accordance with intended counterparts.

Risk communication on the health effects of exposure to low-dose radiation must also take into account psychological and mental factors. In some cases, risk communication may require counseling skills comparable to those possessed by clinical psychotherapists. In other words, risk communicators—or practitioners of risk communication—are highly specialized professionals whose jobs cannot be handled by part-time volunteers. The national government conducts training in risk communication for professionals engaged in healthcare, welfare, and education as well as municipal personnel. However, these stakeholders cannot engage in risk communication on a full-time basis.

Going forward, long-term engagement in nuclear risk communication will be of growing importance to address global challenges related to the management and isolation of radioactive waste, nuclear safety with regard to earthquakes, tsunamis, and other external events, and the fundamental roles of nuclear. Appropriate risk communication materials should certainly be prepared to live up to these tasks. On top of this, a new method needs to be adopted in research and development, and risk communicators will need to be trained on its effective application.

Universities are also expected to offer relevant courses and produce nuclear risk communicators who can overcome global challenges. They should also expand human resource development systems for working professionals in partnership with nuclear regulatory bodies, power utilities, municipalities, and non-profit organizations.

IV. Nuclear Risk Governance

So far, this commentary has discussed radiation risk communication methodology that targets the public as external stakeholders. However, another methodology of risk communication targets members of organizations as internal stakeholders. The NRC in the United States has developed guidebooks [2, 13] on engaging in strategic risk communication with both external and internal stakeholders. These guidebooks are used in the training of NRC personnel.

External risk communication and internal risk communication might seem mutually independent. However, they are integrated as interrelated elements from the perspective of the risk governance discussed in this section, which proposes a new model for nuclear risk governance.

1. Concept of Nuclear Risk Governance

Nuclear risk communication is not a stand-alone practice that exclusively targets external stakeholders. It brings together the domains of risk assessment, risk management, and the public. A strategic approach must be taken for the processes involved in these domains. Moreover, the risk-informed assessment and the decision-making process to deal with the risk should be clarified. Optimal organizational governance should also be explored to ensure transparency for the public.

Many people think that the national government and experts should clarify the risk criteria. However, the public holds a diverse range of values. Some people will accept the presented risk criteria with little objection, but others will remain unconvinced and not accept them.

Most issues associated with nuclear risks are heavily influenced by uncertainties because they fall within the realm of trans-science, which cannot be resolved by science alone. The influence of uncertainties should essentially be considered through interactive dialogue by encouraging people to exercise self-determination through the sharing of unbiased risk-related information, going beyond the conventional approach to risk communication to encourage people to exercise their right to know.

This commentary advances the conventional method of nuclear risk communication, which involves interactive dialogue among stakeholders. It adopts the concept of "co-evolutionary governance" that encourages self-determination to propose a strategic model for participatory risk governance with due consideration given to risk management and social responsibilities, as typified respectively by ISO 31000: 2009 and ISO 26000: 2010. This model is conceptualized in **Figure 2**. To provide an idea of the type of "co-evolutionary governance" involved in the participatory risk governance model, the author will briefly explain how he is conducting community-based nuclear risk communication regarding the health effects of exposure to low-dose radiation with stakeholders in Tsuruga.

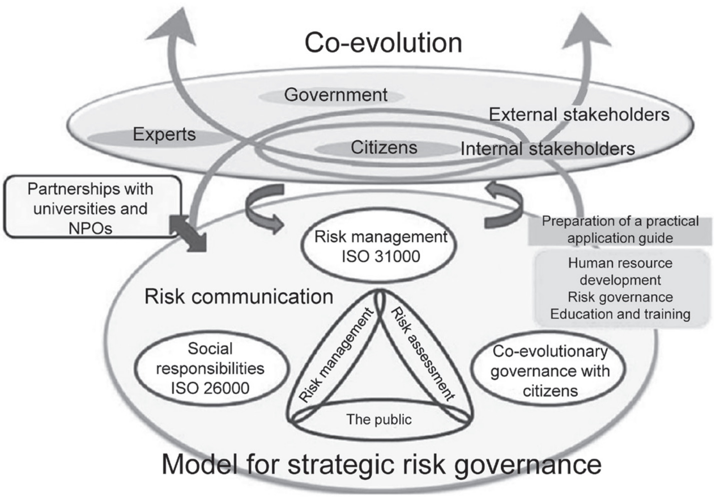


Figure 2 Concept of the model for participatory nuclear risk governance

2. Model for Community-Based Nuclear Risk Communication [14)]

The model employed in community-based nuclear risk communication concerning the health effects of exposure to low-dose radiation identifies the obstacles and challenges faced by the public in recognizing the risks posed by low-dose radiation. In doing this, the model addresses the questions of how information on radiological risks should be provided in a scientifically sound way, how uncertainties that cannot be exclusively addressed by science alone should be handled, and how the psychosocial impact should be taken into account.

To address these obstacles and challenges, study sessions were organized for small groups of local community members to coproduce a guidebook on the health effects of exposure to low-dose radiation.

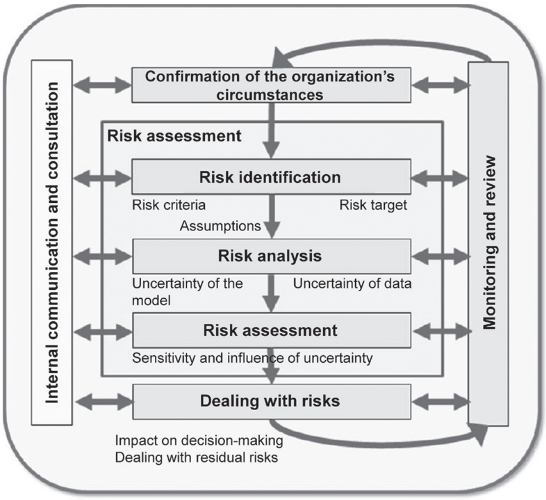
First, a working draft of the guidebook was prepared by researchers involved in radiobiology, sociopsychology, risk communication, public participation, and social responsibilities. The draft was then discussed at the following study sessions involving three groups of several to a dozen citizens from Tsuruga. Group 1 consisted of residents of Tsuruga, Group 2 consisted of public health nurses, registered dieticians, and midwives from the health care center in Tsuruga, while Group 3 consisted of media journalists from the Tsuruga press club. These study sessions were repeated to assess how well local citizens recognized and understood the risks and to discuss the content and wording of the draft guidebook. In fiscal 2013, eight study sessions were held. Citizens and relevant researchers were also invited to participate in discussions at a public symposium in Tsuruga and another one in Greater Tokyo. In fiscal 2014, the draft was jointly revised based on these discussions to compile the introductory part of the guidebook on the health effects of exposure to low-dose radiation. This process was aimed at coproducing a convincing guidebook for participating citizens that would allow them to provide explanations to their fellow citizens.

The process was also aimed at providing a means for diverse actors to coproduce and deliver effective messages on risks as well as to develop a viable model for community-based risk communication.

3. Participatory Model for Risk Governance [15)]

Nuclear risk communication related to earthquakes, tsunamis, and other external events as well as the management and isolation of radioactive waste requires advice from risk assessments and risk management experts, and information from power utilities. This is because the formulation of effective risk messages requires information from each of the processes involved in the performance of risk assessments by power utilities (e.g., risk criteria definition, risk identification, risk analysis, risk assessment, and risk/residual risk resolution) and from internal communications, as shown in **Figure 3**. Power utilities that carry out risk management activities tend to be cautious and defensive in their external communications with the public as they seek to protect themselves from risks. Rather than building mutual trust, this type of nuclear risk communication often leads to confrontation between the two sides.

The proposed participatory model for risk governance seeks to overcome this malady and expand co-evolution with the involvement of local community members, as mentioned in the previous section, even further to develop co-evolutionary governance of the whole community. A third-party organization that is independent of any power utilities, which include social responsibilities, serves as the basic framework for the model. Stakeholders with constructive intentions are fairly represented as members that manage the organization. Power utilities that manage risks are invited to provide relevant risk-related information from their internal



ISO 31000:2009 Risk Management – Principles and guidelines, 2009.

Figure 3 Practical process of risk management

communications in order to prepare and deliver proper and effective risk messages. The management process is clearly communicated to the public to ensure its credibility and transparency. Experts to be consulted on matters related to risk assessments and risk management are chosen through consultation among the members of the organization.

The framework is also aimed at human resource development for the requisite personnel to ensure that they can carry out nuclear risk communication effectively. The development of a new model for nuclear risk governance will be pursued by clarifying the details of its framework and processes as well as how these processes will be interlinked. Examples of this include how the organization will be structured, how neutral management will be ensured, how stakeholders can be involved in an equitable manner, how the power utilities will cooperate, and how accountability and transparency will be ensured. If we take the local information committees found in France as an analogy, the idea is to encourage the participation of local assembly members as stakeholders.

In this respect, a similar effort should probably be made by the nuclear regulatory bodies with a mandate to protect people's lives, health, and the environment. The author is curious to know whether readers share his belief that nuclear regulatory bodies must live up to their missions and fulfill their social responsibilities to clearly explain their regulatory standards and the outcomes of conformance reviews by going beyond the simple publication of information.

V. Conclusions

The issues and challenges associated with conventional nuclear risk communication were discussed based on the experience of risk communication concerning explicit radiation in the aftermath of the Fukushima Accident. This commentary also proposed a participatory model for nuclear risk governance over the long-term to manage and isolate radioactive waste, ensure nuclear safety with regard to earthquakes, tsunamis, and other external events, and continue nuclear risk communication concerning the fundamental roles of nuclear.

As typified by the debate over the possible resumption of nuclear power in Japan, the use of nuclear power tends to invite confrontation between two camps that seem unable to reach a constructive solution. Nuclear risk communication is a social technique that is used to share unbiased risk-related information among stakeholders, build up mutual trust through mutual understanding of their different values, and lead them in a constructive direction. It is not intended to convince others or reach a rough-and-ready consensus. Although it may seem a roundabout way of doing things, it is actually the most reliable and fastest way to reach consensus while avoiding conflict and the associated social costs. The essence of this approach is mutual respect for differing opinions among stakeholders and acknowledgement of the fact that their values can change through interaction.

Everyone would agree that we share a common goal of wanting to build a society in which people can feel safe, thrive, and pursue happiness. The author hopes that constructive nuclear risk communication will prove conducive to achieving this goal.

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Commentary

Radiation Health Risk Communication in Nagasaki University/Kawauchi Village Reconstruction Promotion Base

Nagasaki University, **Makiko Orita**

In March 2011, an accident occurred at the Fukushima Daiichi Nuclear Power Plant, which is operated by the Tokyo Electric Power Company, due to the Tohoku earthquake and ensuing tsunami (such accident being hereinafter referred to as the "Fukushima Daiichi Nuclear Accident"). The resultant environmental release of invisible, scentless radioactive materials, which are undetectable by human senses, caused a serious panic among the public. The incident created public interest in radiation health risk communication, which addresses the health impact of exposure to radiation. According to conventional wisdom, radiation health risk communication is pursued among experts, government officials, and community members with the aim of sharing information on the health risks posed by radiation and making mutual communication among them. Today, radiation health risk communication tailored to the living conditions and ideas of individuals according to the air dose rates and exposure dose rates seems to be of increasing importance.

On April 20, 2013, Kawauchi Village in Futaba, Fukushima Prefecture, signed an agreement with Nagasaki University on comprehensive cooperation. Since then, the author has engaged in various healthcare activities at the reconstruction promotion base of Nagasaki University that they established in Kawauchi Village to protect community members from the health risks associated with radiation. This commentary summarizes these activities.

I. Kawauchi Village in Futaba, Fukushima Prefecture

Kawauchi, a village located in Futaba, Fukushima Prefecture had a total population of about 3,000 when the disaster hit the area. This scenic part of the countryside is nestled in the hills alongside the Abukuma Mountains in the prefecture's Hamadori region. It lies within 20 to 30 km of the Fukushima Daiichi Nuclear Power Plant. Affected by the Fukushima Daiichi Nuclear Accident that occurred in March 2011, all of the village members, along with the village office personnel, evacuated to Koriyama (which is located in the same prefecture). In January 2012, Kawauchi Village declared before any other village its intention to allow its citizens to return home in light of the relatively low air dose rates there. The village office

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moved its administrative functions back to Kawauchi from Koriyama at the end of March 2012 while encouraging community members to return home whenever they were ready. Efforts have been steadily made to plan the decontamination work, restore farming and forestry, and stimulate local commerce with the aim of rebuilding the community.

As of January 2015, about 1,600 residents of the total population of roughly 2,700 have returned to Kawauchi. A gradual return has continued since the official declaration was made. However, about 40% of the villagers continue to live in other municipalities as evacuees. The possible causes of their reluctance to return home almost certainly include concerns over the village's educational and healthcare infrastructure as well as convenience in their daily lives. However, they might also have been discouraged by risks associated with the decommissioning work being carried out at the Fukushima Daiichi Nuclear Power Plant and concerns over the health effects caused by exposure to radiation.

II. Kawauchi Village Reconstruction Promotion Base of Nagasaki University

Since December 2011, Nagasaki University has been assisting in the reconstruction efforts carried out by Kawauchi Village. For instance, the university estimated the exposure dose rates among residents to establish scientific grounds for their intended return by measuring the radioactive materials contained in the soil in December 2011. The university communicated these findings to village residents at lecture meetings and the like. It also provided scientific support for efforts by village members to return home and restore their community.

On April 20, 2013, Nagasaki University and Kawauchi Village signed an agreement on comprehensive cooperation for the restoration and revival of the local community. In the village, the Kawauchi Village Reconstruction Promotion Base was established as a satellite facility of Nagasaki University. This base works closely with the village office to measure radioactivity in the soil and food to ensure the safety of residents as well as offer radiation health consultation services based on the measurement data. At the base, local health nurses work with experts in community-based rehabilitation and community heath from Nagasaki University's School of Medicine (health nurses, physiotherapists, and occupational therapists). They organize various health counseling sessions, exercise therapy, and other health-promoting activities in combination with social gatherings and other events for community members. Notably, the base brings together experts (from Nagasaki University) and the local government (village office of Kawauchi) to promote local reconstruction. This expert-government partnership is expected to facilitate effective radiation health risk communication.

III. Activities Involving Radiation Health Risk Communication

At the Kawauchi Village Reconstruction Promotion Base, the author has engaged in healthcare activities to protect community members from the health risks associated with radiation. This engagement began when the author stayed in the village for a month from May 2012 immediately after the evacuees had begun to return. As part of the field practice element of her master's program, she worked with local health nurses to provide health consultations on radiation and perform door-to-door visits. When the village and Nagasaki University signed the cooperation agreement in April 2013, she was permanently assigned to the satellite base to continue her work there. Local health nurses conduct a wide range of healthcare activities, including maternal and child healthcare, geriatric healthcare, mental healthcare, community health promotion, and infection control. The satellite base mainly took charge of healthcare activities for the provision of protection against radiation. Located in the only city other than Hiroshima to have been attacked with an atomic bomb, Nagasaki University has been studying the health impact of radiation exposure and the carcinogenic mechanism of radiation. It has also played a role in the provision of healthcare to atomic bomb survivors. The university is expected to apply their findings and engage in tangible activities in response to the Fukushima Daiichi Nuclear Accident. The satellite base, which is situated in the community center (locally known as *Nakayoshi-kan*) near the village office (**Figure 1**), is gradually gaining recognition among residents thanks to the public relations activities conducted through the village office and the announcements made at the social gatherings that are frequently organized in the village and at shelters for evacuees from the village.

In most cases, teams from the base conduct door-to-door visits to provide consultation services. Residents often ask questions such as whether the water and rice are safe for consumption, whether children can touch insects, and whether any decontamination work was carried out after the atomic bomb was dropped on Nagasaki. The teams also attend social gatherings organized by the village to support evacuees, discuss future land use, and other such purposes (**Figure 2**). At these gatherings, the teams respond to questions from residents related to radiation and health as well as distribute dosimeters that have been donated for the residents along with the instructions for their proper use (**Figure 3**).

During consultations on health and radiation, people often ask how they should interpret the various figures. The nuclear accident was followed by panic and a flood of information and unfamiliar terms, such as μSv, Becquerel, and internal exposure. As time went by, air dose detectors were deployed all over Fukushima Prefecture. Furthermore, local dose rates are reported daily in detail by newspapers. In fact, dosimeters are so widely used that almost every villager from Kawauchi has at least one personal dosimeter, which means that they can find out their own radiation doses. Nonetheless, measures aimed at helping them to interpret these doses are falling behind. Given this situation, Nagasaki University has prioritized healthcare activities aimed at helping people learn how to interpret these figures.

The conducting of dose assessments is an important starting part for radiation health risk

Figure 1 A community center where the satellite base of Nagasaki University is situated. (Kawauchi, October 2013)

Figure 2 A briefing session for local residents at a community hall (Kawauchi, June 2014)

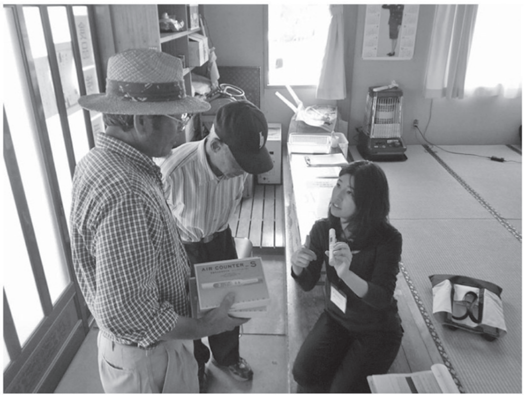

Figure 3 Distribution of dosimeters at a community hall (Kawauchi, June 2013)

communication. The base teams conduct measurements of the air dose rates at the homes of villagers and in the surrounding areas. They also bring back soil and vegetable samples for radioactivity measurements. The teams present these measurements to villagers and explain what each of the figures indicates. In this manner, the teams address the villagers' questions and concerns over radiation exposure in everyday life. The villagers often comment that they feel reassured if they can understand the levels of radioactivity in local soil and food.

In May 2014, a germanium detector was installed and put into service in Kawauchi Village thanks to the cooperation of the Nuclear Safety Research Association. So far, Kawauchi Village has deployed a simplified detector in each district and conducted radioactivity tests on food. At the request of the villagers, Nagasaki University also conducted radioactivity measurements back in Nagasaki by sending the food entrusted to them there. In addition to the ongoing food tests, the germanium detector has also made it possible for much-needed measurements on soil and water to be performed quickly. Health consultations and other forms of radiation health risk communication should probably be based on objective numerical assessments of the radiation.

IV. Efforts to Facilitate a Return to the Evacuation-Directive Area in Kawauchi Village

Kawauchi Village had been zoned as a “restricted area” and an “evacuation-prepared area in case of emergency” since April 2011. The latter designation was lifted in fall 2011. The restricted area within 20 km of the Fukushima Daiichi Nuclear Power Plant was rezoned as an “area in which residents are not permitted to live” and an “area to which evacuation orders are ready to be lifted” in April 2012. In both cases, residents have been permitted to freely access their homes, but not stay there overnight. Meanwhile, due to encouraging signs that the decontamination work is near completion, efforts have been made to support the return of evacuees to these areas in Kawauchi.

The various studies conducted after the nuclear accident revealed that the measured personal doses do not necessarily match the exposure doses estimated from the air dose rates based on the assumption that residents will exhibit the same behavior and that homes will have the same shield factor [1)]. For this reason, Fukushima is expected to facilitate the return of willing evacuees by implementing the necessary measures while paying attention to their individual exposure doses. To this end, Nagasaki University has been assessing the environmental radioactivity and individual exposure doses in the evacuation-directive area. More specifically, the university has distributed personal dosimeters to residents with special permission to stay in their homes overnight during occasions such as the New Year holidays. Their individual doses have been assessed to estimate their annual exposure doses. In combination with an assessment of the air doses and analysis of the radionuclides in soil, the validity of a return to the evacuation-directive area has been evaluated.

To date, personal dosimeters have registered, in annual terms, a minimum annual dose of 0.71 mSv, a maximum dose of 2.15 mSv, an average dose of 1.25 mSv, and a median dose of 1.21 mSv. The annual average dose slightly exceeds the annual exposure dose limit of 1 mSv for the public under ordinary circumstances, as set by the International Commission on Radiological Protection (ICRP). However, such a dose proved extremely limited. Meanwhile, air dose rates were measured when villagers were given special permission to stay home overnight when they returned home temporarily. The total annual dose in each house was calculated based on measurements taken outside the front doors of houses, behind the houses, and in fields. In annual terms, the measurements taken outside the front doors registered a minimum dose of 0.88 mSv, a maximum dose of 1.75 mSv, an average dose of 1.14 mSv, and a median dose of 1.04 mSv. These figures were almost comparable to or slightly lower than the measured individual exposure doses. This is probably due to the successful dose reduction achieved by the almost complete decontamination of houses in areas to which evacuation orders are ready to be lifted. Similarly, the measurements taken behind the houses registered a minimum dose of 0.99 mSv, a maximum dose of 2.15 mSv, an average dose of 1.63 mSv, and a median dose of 1.58 mSv. The measurements taken in fields registered, in annual terms, a minimum dose of 1.45 mSv, a maximum dose of 3.29 mSv, an average dose of 1.82 mSv, and a median dose of 1.77 mSv. As expected, the doses recorded in fields were slightly higher than the ones recorded around the houses. Based on these measurement results, the annual external exposure doses are expected to be within the range of 1 to 2 mSv at most, which validates the return of evacuees to their homes. The massive epidemiological studies that have been conducted so far on atomic bomb survivors from Hiroshima and Nagasaki revealed that survivors experienced an increase in cancer risk in proportion to any exposure doses in excess of 100 mSv at one time. However, no increase in cancer risk has been proven with an exposure dose of below 100 mSv. The ICRP has set a limit of 1 mSv as an acceptable annual exposure dose for the public under ordinary circumstances to minimize any additional exposure to radiation. It must be noted, however, that the cancer risk resulting from such exposure does not begin to increase from this threshold of 1 mSv. Moreover, during a radiation disaster, the ICRP recommends that the limit for the annual exposure dose be assigned to the lowest possible level of between 20 to 100 mSv. Once the disaster has been brought under control, the ICRP recommends that the annual limit be gradually reduced before it ultimately reaches 1 mSv. Given the outcomes of earlier decontamination work and other efforts to reduce exposure doses in Kawauchi, the village office deemed it appropriate for evacuees to return home as long as the effects of decontamination are continuously evaluated, infrastructure is steadily improved, and the community is rebuilt under the ongoing partnership among residents, the village office, and experts from various fields. Accordingly, the designation of "the area to which evacuation orders are ready to be lifted" was lifted on October 1, 2014. Nonetheless, the monitoring of external exposure doses should be continued in response to any later requests from villagers along with the provision of fine-tuned consultation services according to exposure doses.

The establishment of a satellite base by Nagasaki University in Kawauchi Village to act as a frontline for post-disaster reconstruction efforts made it possible to keep track of the needs of local residents and any questions that they encountered, thereby facilitating radiation health risk communication. Furthermore, a backup system for the university staff that permanently stays at the village was gradually brought online to enable resident personnel to consult with experts in Nagasaki University and address any issues and/or questions that they may encounter during the performance of local activities while identifying the needs of the villagers. Almost five years after the disaster, many more evacuees are expected to return to the municipalities situated around the Fukushima Daiichi Nuclear Power Plant. Assistance for these returning evacuees must be carefully planned. The national government is planning to assign community counselors on radiation exposure and health. Their assignments will probably need to be clarified, and the necessary backup system should be established for them. In light of the need for long-term assistance, urgent human resource development in the field of radiation exposure medicine and healthcare professionals is needed to ensure that they are adept in radiation emergency medicine. The healthcare system in Fukushima is clearly being dutifully underpinned by the Fukushima Medical University in Fukushima City. This university is expected to lead the process of building up the more necessary systems. At the same time, a collaborative system should be established between counselors and experts as a part of a bigger framework for supporting the university.

V. Challenges Ahead

In radiation health risk communication, it is important to respect the views that each of the local residents has concerning exposure to radiation and their ultimate decisions as to whether to return home or remain as evacuees. Healthcare professionals and experts must help local residents to make informed decisions.

Meanwhile, attention has been drawn to the dire shortage of experts who can engage in radiation health risk communication. One of the challenges that lie ahead is how these experts should be developed. Public health and other nurses are known to be familiar with the actual living conditions in the local communities there, so they play extremely important roles during a nuclear disaster and in every step of the reconstruction process. Unfortunately, these nurses had not received much education in radiological protection, let alone radiation emergency medicine. As an educational institution situated in a city that has suffered from an atomic bomb attack, Nagasaki University has been conducting lectures on radiation exposure and nursing for almost a decade as part of an undergraduate program in its School of Health Sciences. These lectures are intended to help students gain a deeper understanding of their expected roles in radiation emergency medicine as public health and other nurses in the future. This type of undergraduate program is offered in only a few universities. In 2010, Nagasaki University began offering a master's course for the development of public health and other nurses specializing in emergency radiation medicine. The author has also attended this course to acquire a basic understanding of radiological protection and radiological impacts as well as to study the roles that public health and other nurses are expected to fulfill in the provision of radiation emergency medicine. Having completed the master's program there, she is now enrolled in a doctoral program at the Atomic Bomb Disease Institute in the same university. At present, only three universities in Japan—Hirosaki University, Nagasaki University, and Kagoshima University—offer master's courses in radiation nursing. The annual course enrollment numbers account for only a few students in each graduate school. In light of the long-term continuous efforts that are required for reconstruction after a nuclear accident, it is becoming ever more important to involve public health and other nurses together with other healthcare professionals who are familiar with radiation emergency medicine. As evacuees from Fukushima Prefecture municipalities situated within 20 km of the disaster site continue to return to their homes, such personnel all play essential roles. Having acquired the minimum level of expertise required in radiological protection and radiation emergency medicine, public health and other nurses are not only able to provide better healthcare under ordinary circumstances, but also well placed to help plan how experts are mobilized in nuclear disaster management.

VI. Conclusions

In the practice of radiation health risk communication, local government agencies and experts should work together to attentively support local residents. Furthermore, with radiation health risk communication in post-disaster reconstruction continuing to attract increasing attention, the relevant activities conducted in Kawauchi Village could serve as a model for further reconstruction efforts throughout the rest of Fukushima.

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Commentary

Health Impact Caused by a Nuclear Disaster

–Preventable Deaths and Illnesses–

Soma Central Hospital, **Sae Ochi**

The damage caused by a nuclear disaster is quite complex, and it extends far beyond health damage from radiation. In the specific case of the Fukushima nuclear disaster, no comprehensive assessment has been conducted to examine the health damage caused by the misguided evacuation plan. In the ongoing debate over the pros and cons of the possible resumption of nuclear power, we may be distracted by the issue of radiation and lose sight of something important. The author, who lives in Soma, Fukushima Prefecture, describes the health damage that resulted from the evacuation conducted in response to the nuclear accident based on findings gained from her fellow local professionals.

KEYWORDS: nuclear disaster, mass evacuation, health, disaster risk reduction, public health

I. Introduction

We often hear of the increasing likelihood of the resumption of nuclear power. Personally, I am not in a position to know what is really going on and who would make such a decision.

A discussion of the pros and cons of this resumption is certainly important. However, anyone with a background in disaster public health can see that the possible resumption of nuclear power and the potential occurrence of nuclear accidents can be considered quite similar to a natural disaster in the eyes of the public. The reason for this is that nuclear accidents happen when they do whether people like it or not.

Even if Japanese nuclear power plants do not resume operation, many other such plants are in operation throughout the world. Probably the only option that we have now is to be as well prepared for the future as possible based on the lessons learned and wisdom gained from our experience of the Fukushima Nuclear Accident.

Preparations for the resumption of nuclear power essentially involve the development of adequate measures against nuclear accidents. In the aftermath of the Fukushima Daiichi Nuclear Accident, many people lost their lives in the secondary disaster caused by a misguided evacuation plan. Their number far exceeds the reported number of victims of radiation

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exposure to date. The health damage that they suffered mostly passes unnoticed by stakeholders of the nuclear sector, who are distracted by debates over radiation.

What should be learned from the experience of the Fukushima Nuclear Accident and what measures should be reinforced to prevent the secondary disasters that would inevitably follow another nuclear accident? Let us examine some examples of the health damage caused by the emergency evacuation and prolonged evacuation of local residents to address these questions.

II. Damage Caused by the Assignment of Evacuation Zones

Soon after the nuclear accident, the government of Japan assigned evacuation zones that were defined mostly by concentric circles that indicated three different levels of measures. Forced evacuation was imposed in the restricted area up to 20 km from the accident site. Sheltering was ordered in the "evacuation-prepared area in case of emergency" (an evacuation zone designated in anticipation of a further emergency) within a range of 20 to 30 km from the site. The "deliberate evacuation area" (a zone assigned for planned evacuation) was designated within a range of 30 to 50 km from the site.

The designation of evacuation zones based on concentric circles and the adequacy of the distance of 20 km are often debated. However, this commentary does not discuss the illogical zoning, as it did not directly cause any significant health damage among the residents.

In my opinion, the failure to prevent the recent secondary disaster was mainly due to two incorrect assumptions about the evacuation zones.

Firstly, the restricted area was designated based on the unwarranted assumption that residents would be able to evacuate in unison under the same conditions. Secondly, the evacuation-prepared area was mistakenly assumed to have a clear-cut borderline.

1. Vulnerable People Left Behind in the Restricted Area

The municipalities of Minamisoma, Fukushima Prefecture, were divided into different evacuation zones. Fortunately, all the rescue crews stayed put in the communities affected by the earthquake-induced disaster, and ambulance transportation was still intact even after the nuclear accident. The author would like to deeply appreciate the incredible efforts made by the rescue crews, who were also victims themselves.

According to their records, six ambulance calls were made from people inside the restricted area within a week of the evacuation zones having been designated. Clearly, the evacuation order issued by the government was not thoroughly carried out on the ground. Special note must be taken of the fact that most of the people that remained there did not necessarily do as out of choice.

The "information poor" are the most vulnerable to disasters. For example, elderly people with hearing impairments may often fail to notice evacuation advisories and end up being left behind during a mass evacuation. Some even need assistance just stepping outside the door to their house, such as the bedridden elderly and those who rely on home-care ventilators. One family explained that they were completely confused during the evacuation. They actually left behind a bedridden family member with some food at his bedside, only to find out later that they could no longer return to their home.

Evacuation advisories were not announced door to door to make sure that everyone was informed. Even if they had found people who needed special assistance, it would have been impossible to rescue them all.

It is not clear how many people within the 20-km range had to die at home alone without being able to call an ambulance. However, such solitary deaths were not limited to the restricted area. Some vulnerable people were “forgotten” even in other more accessible areas.

2. Confusion Caused by the Sheltering Order

The chaos that accompanied the forced evacuation was eclipsed by the social upheaval caused by the sheltering order issued in the evacuation-prepared area within a range of 20 to 30 km from the accident site.

The order for sheltering-in-place may well have been scientifically justified as a means of securing a dramatic reduction in external radiation exposure. In reality, however, it threw society into a great panic.

For instance, most business operators have forbidden their personnel from entering a 50-km range from the nuclear power plant since the designation of the evacuation zones. Some personnel probably refused to enter there out of their own fear of radiation. In other cases, companies might have imposed this ban out of a sense of duty to ensure the safety of their personnel. Amidst the mistrust of information provided by the government and the media, private companies naturally designated much more extensive evacuation zones than the official ones.

As a result, people in the evacuation-prepared area within a range of 20 to 30 km were cut off from the distribution network even though they were allowed to reside there. The denial of access to food for their survival was aggravated when gasoline deliveries were cut off. Despite having access to electricity and water in the area and being legally allowed to reside there, they were effectively denied the chance to live there.

“If we don’t evacuate now, we will be left behind.” This fear gave rise to further panic and resulted in almost all of the residents who were mobile evacuating the area.

Vulnerable people were left behind due to the disaster, including solitary elderly people with poor access to information, people without cars, hospitalized patients, and hospital personnel. A doctor who was assigned to Minamisoma at that time recalled the following: “I performed almost all of the autopsies in Minamisoma within a 30 km radius for a month after the earthquake-induced disaster. Without access to food, many elderly people I saw had starved to death at or near their homes.”

III. Harm Caused by the Evacuation

Aside from the vulnerable people who had been left behind, many evacuees were also affected by a secondary disaster. A particularly serious problem was health damage to the elderly.

Main problems clarified to date involved the evacuation of patients from healthcare facilities such as elderly people, nursing home and hospitals, the loss of access to medical care needed by patients with chronic diseases, and the prolonged evacuation of healthy elderly people.

1. Harm Caused by the Evacuation of Hospitalized Patients

The social panic at that time compelled many healthcare facilities for the elderly to evacuate patients in ordinary passenger cars that were unequipped with mattresses and the like. Many patients lost their lives lying across the seats of a minibus during a long-distance evacuation.

Moreover, the 60% of hospitals in Japan that are privately managed probably cannot count on swift emergency support from public institutions. Every hospital interviewed by the author had to mobilize their personnel and their personal connections to coordinate car transportation and find new host facilities for the patients. Hospitals without a strong network took a very long time to decide on the destinations for their patients. Hampered by the conducting of radiation exposure surveys and the congested roads, the transportation of patients took more than 10 hours, all without adequate provisions for blankets, water, and the necessary equipment. According to a report by the Diet Accident Investigation Committee, over 40 patients lost their lives while they were being evacuated from their original hospitals before reaching their destination hospitals [1].

Moreover, a rise in the mortality rate was reported among patients after their evacuation, because of inadequacies in the handover between hospitals and sudden changes in their environments. After long periods of hospitalization, some elderly patients fail to eat their meals if there is even a slight difference in the meal preparation or assistance. Furthermore, transporting elderly patients without periodically changing their positions can heighten the risk of bedsores and aspiration pneumonia.

For instance, a study conducted by Nomura et al. to investigate the evacuation of patients from seven long-term care facilities in Minamisoma [2] found that the mortality rate over the course of one year after their evacuation more than doubled compared to the level before their evacuation.

2. Harm Caused by the Evacuation of Chronic Disease Patients

Inadequate access to proper medical care in the midst of such a panic caused health damage to many patients with underlying diseases who could otherwise have led normal lives. The most notable examples of this are dialysis patients.

At my workplace, Soma Central Hospital, they say that the water supply was disrupted for a few days after the earthquake and that they experienced a serious shortage of water that was needed to operate the dialyzers. “Fortunately, water was still supplied to the opposite side of the national road, so when a water tank truck reached our hospital, we used the entire supply of water from that truck to operate the dialyzers,” said one member of the hospital staff recalling this challenge. “We also asked patients who had a stable condition to bear with a prolong dialysis cycle. Our dialyzers were overextended due to the new arrival of dialysis patients from Minamisoma. There was also a patient from Iwate (which also suffered tsunami damage despite being located 200 km to the north of Fukushima) who had travelled south while searching for an alternative dialysis facility in one place after another before reaching us…”

Special care needed to be taken not only for dialysis patients, but also for elderly people who were reliant on home oxygen therapy and tubal feeding. Health damage can also be caused by an interruption to the administration of agents for treating basic diseases such as diabetes and high blood pressure. No report has been obtained to determine whether all of the patients who required home oxygen therapy in the evacuation zones were able to remain safe without access to care services provided by outside contractors.

In fact, patients with chronic diseases often encounter such problems during a major disaster that involves mass evacuation. A review [3] of papers from Japan and other countries that was conducted by the author and her colleagues revealed that chronic diseases required a substantial proportion of the medical care provided in the aftermath of the 2011 Great East Japan earthquake. Numerous cases of health damage reported from recent major disasters, including the latest earthquake-induced disaster in East Japan, involved the loss of medical devices (e.g., regular medication, allergy medication, and other emergency medication, including assistive devices, such as glasses, dentures, and canes) [4]. Many people from the Miyagi coast and other coastal areas where the 2011 Great East Japan earthquake and tsunami struck faced problems as they left their therapeutic agents at home [5]. A similar situation is expected to arise for evacuees from Fukushima who had to engage in a mass evacuation without adequate preparation.

3. Harm Caused by the Prolonged Evacuation at Temporary Shelters

In addition to patients with underlying diseases, elderly people who were initially healthy were also affected by the prolonged evacuation at temporary shelters.

Life in a temporary shelter poses various types of health risks. One of the most crucial factors is that indoor activity inside one-storied temporary shelters with an area of just 30 m^2 is extremely limited. The geographical locations of the temporary shelters can also be a cause of reduced activity. It has been reported that good access to restaurants, grocery stores, and convenience stores play an important role in keeping the elderly active [6, 7]. At remote temporary shelters located at some distance from the local communities, evacuees become dependent on car transportation to compensate for the poor access to shops. As a result, their levels of activity may be diminished considerably. Some evacuees from coastal areas explained that they felt unable to leave their temporary shelters in the mountains because they were afraid of wild boars and pit vipers.

This lack of physical activity became glaringly apparent in the checkup of locomotor systems that was conducted in Soma in 2012, a year after the earthquake-induced disaster. Among people aged 65 and older, evacuees living in temporary shelters proved to have a five times greater risk of experiencing a reduced ability to stand on one leg with their eyes open than was the case for their peers who had remained living at home (data sourced from a paper being submitted by the author and her colleagues). In contrast, evacuees living in temporary shelters exhibited a significantly greater grip strength than other residents. Given that most evacuees living in temporary shelters used to engage in agriculture and fisheries, these findings seem to suggest that formerly strong people who had been engaged in the primary sector of the economy are quickly losing their leg strength while living in temporary shelters.

Life as an evacuee also leads to changes in diet. Before their evacuation, these people used to consume locally produced food, with many of them refusing to buy fish and vegetables from supermarkets as they are “expensive and taste lousy.” Furthermore, the long distance to the supermarkets meant that evacuees also began to consume less vegetables and perishable food in an effort to stock up on food in the shelters. As a result, they have an unbalanced meat-heavy diet today. Worse still, concerns over radiation discourage people from consuming healthy ingredients, such as fish, vegetables, mushrooms, and fruits, even when they are on the market. Health checkups in Soma demonstrated that high blood pressure, diabetes, and obesity could be observed among a greater share of evacuees living in temporary shelters than among local residents [8]. Given this, there are concerns that this prolonged evacuation may increase the prevalence of chronic diseases.

Lastly, the evacuees have also suffered mental harm. The losses caused by a disaster are known to trigger depression. People did not only lose their property due to the forced evacuation, farmers and fishers lost their jobs when the nuclear disaster put an end to the primary sector. Furthermore, their prolonged evacuation is adding to their psychological stress. When the author participated in a health checkup at a temporary shelter, one person told her: "I seldom go out for a walk because I cannot bear the sight of my house on the way back to the shelter." This is just one example of the damage to mental health that this prolonged evacuation has caused.

IV. Difficulties Involved in Planning The Evacuation in Fukushima

The preceding section provided an overview of the health damage caused by the evacuation conducted in response to the Fukushima Daiichi Nuclear Accident. Has the evacuation plan been improved based on these experiences? Unfortunately, the answer to that question is "no" at the moment.

Take Soma, where I live, for instance. Parks, schools, and other public spaces are equipped with NaI scintillation detectors for measuring the air dose rates. Such a measure is certainly important in enabling people to find out the levels of local contamination on the spot. Unfortunately, however, no guidelines have been presented to explain how these measurements should be applied in practice. In other words, no guiding benchmarks have been set in the units of μSv/h to allow residents to decide whether they (and children in particular) should evacuate if the dose rate exceeds a certain level.

People living in Hamadori, an area of Fukushima located along the Pacific coast, best understand the difficulty involved in setting such a benchmark. "Suppose a benchmark is set on a scientific basis to initiate an evacuation at a certain dose level. In practice, no residents would wait until the dose rose to that level." Mr. Hidekiyo Tachiya, the mayor of Soma, points out the problems associated with numeric targets while acknowledging their importance. "A voluntary evacuation would be prompted by a dose level much lower than any benchmark. It is easy to imagine that vulnerable people would be left behind yet again. The earlier chaos experienced with the sheltering order discourages us from setting any guiding benchmarks."

This paradox stands in the way of performing radiation surveillance using scintillation detectors and other means in Fukushima.

V. Lessons to be Learned from Fukushima

What can be learned from these experiences in Fukushima? The disaster can arguably be said to have shed light on the issues described below.

1. Designation of Evacuation Zones

Along with the assignment of relevant ranges (e.g., distance and dose level), evacuation zones must be designated with due consideration given to the problems induced by these demarcations. Any discussion of the appropriate distance probably does not carry much practical significance.

(1) Removing obstacles to distribution

The matter that requires the most consideration is the way in which distribution and the necessary personnel are maintained in the outer rims of the evacuation zones. As mentioned earlier, private companies are likely to set a wider evacuation zone than those designated by the government. Furthermore, no one has the authority to order distributors and healthcare professionals (especially female nurses) to go to the peripheries of the evacuation zones given the risks of radiological contamination. In this respect, it is safe to say that the distribution systems in the evacuation zones today depend solely on the goodwill of residents. This must be reformed as soon as possible.

(2) Preventing vulnerable people from being left behind

During a disaster, caregivers and other care workers are also affected on the ground. It is completely unreasonable to expect them to escort all of their patients in the midst of all the chaos. The care workers could be mentally overwhelmed. Given its rapidly ageing society, Japan must take note of an increase in the number of vulnerable people during an emergency.

2. Planning of Evacuation Activities

Adequate evacuation planning is impossible without a prior assessment of the potential health damage caused by evacuation activities.

At present, however, almost no study or analysis has been conducted from a bird's-eye perspective regarding the health damage caused by the nuclear disaster.

(1) Planning evacuations from care facilities

As explained earlier, an evacuation can increase the mortality risks for the elderly. Does that mean that long-term care facilities should delay an evacuation? If so, care workers and distributors of food and other items would also have to remain there. Without the appropriate authority, nobody can guarantee that vulnerable people would receive the adequate assistance they need. A more sensible alternative may be to minimize the burden on evacuees by, for example, securing the necessary items and vehicles, arranging the destinations efficiently, and preparing handover templates.

(2) Planning evacuations to temporary shelters

Any prolonged evacuation after a disaster also leads to an increase in the number of deaths caused by musculoskeletal disorders, lifestyle diseases, heatstroke, cold weather, and other environmental factors. In fact, in Fukushima Prefecture, the number of people who lost their lives from indirect causes in the aftermath of the earthquake-induced disaster exceeded the number who died from direct causes during the disaster[9]. This is considered to be due to prolonged evacuation, which poses greater disease risks.

As matters stand today, the health damage caused by the disaster has not even been quantified. Aside from the identification of risk factors, efforts must be made by the relevant organizations to swiftly resettle evacuees in permanent housing, improve their access to shops and medical services, and help rebuild their communities.

VI. Turning the Disaster into a Positive Legacy

"Who should take the lead in solving these problems?" People often ask me this question when I talk about the health damage caused by the nuclear accident. However, Japanese society will fail to learn any lessons from the last disaster as long as people remain on the sidelines and expect somebody else to take care of these problems. Indeed, health is everyone's business.

Some may think that health should be left to the healthcare professionals. However, the basic duty of a doctor is to diagnose diseases at a hospital, and diseases are just one aspect of health damage. In my capacity as a doctor, I have focused my attention on diseases and deaths in this commentary. However, health is not maintained simply by preventing diseases. Rather, the bedrock of health is formed through access to adequate food, clothing, shelter, and mental fulfillment as well as education. Naturally, the nuclear sector, which is also represented by readers of this journal, must assume important responsibilities and roles in the safeguarding of people's health by maintaining a robust social infrastructure.

For instance, distribution in the outer rims of evacuation zones and the means of transport for evacuees could be secured with the assistance of a power utility company. In the event of a nuclear accident, food and supplies for workers must also be brought into the relevant nuclear plant. Perhaps distribution channels could be integrated with the logistics network for local residents.

To ensure the health of local residents living in the environs of a nuclear power plant, it is vital for various professionals from the public and private sectors to cooperate on a regular basis to improve community healthcare. After all, healthy local residents will suffer less health damage. Multiple-disciplinary cooperation is necessary to keep communities healthy and prevent diseases. This is common knowledge in the public health field. Everyone is expected to reflect on the professional contributions that they can make to protect people's health.

Lastly, on a more personal note, I wonder if our healthcare system could be maintained in collaboration with a variety of professionals. Healthcare services in Fukushima had already been pushed to the brink of collapse before they were further overwhelmed by the nuclear disaster. The resultant breakdown stands in the way of the reconstruction of local communities. Residents of difficult-to-return zones are reluctant to return home even if evacuation orders are lifted partly because of poor access to healthcare and welfare services. In Fukushima, nurses and caregivers, who are predominantly women, have little incentive to continue providing healthcare assistance. Healthcare professionals could perhaps be more motivated by the provision of better management, guidance by sales professionals, and material assistance.

Much more wisdom is needed today to prevent health damage from nuclear disasters. Without excluding anyone as an outsider, all kinds of professionals should be invited to combine their specialist knowledge. By adopting this approach, I believe that we will be able to find the right approach to post-disaster reconstruction efforts and the necessary disaster management measures.

VII. Conclusions

This commentary examines how mass evacuation causes health damage based on the experience gained in the aftermath of the Fukushima Nuclear Accident based on survey results, facts obtained from interviews, and some personal observations.

Radiation is not the only challenge posed by a nuclear accident. In fact, social, economic, psychological, cultural, and other factors are intricately intertwined. There is no silver bullet (specific medicine/unique answer) for dealing with such a complex disaster. To build a more prosperous society by heeding the lessons learned from previous disasters, professionals from every field should combine their knowledge and skills to achieve the common goal of protecting people's health. In any future nuclear accident, what can we do to prevent health damage like that experienced in the last disaster? I hope that a number of professionals will draw on their collective expertise to answer this question.

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Risk Communication for Stakeholders Making Decisions about the Energy Future with Atomic Power (2)

−Risk Communication Activities Based on Lessons Learned from Accident Response at Fukushima Daiichi NPS−

Tokyo Electric Power Company, **Tomoki Usui** and **Takashi Yamamoto**

The Tokyo Electric Power Company (TEPCO) has been promoting risk communication by heeding the lessons learned from the Fukushima Daiichi Nuclear Accident. Based on the assumption that there is no such thing as absolute nuclear safety, risk communicators have been appointed to coordinate specific measures with the Social Communication Office established in the company. Both in coordination with each other are assigned to cultivate the social sensitivity of the Nuclear Power Department and the company as a whole to ensure that their way of thinking and criteria for judging are not out of touch with the rest of society. This commentary presents a series of dialogues that have been pursued with communities in Fukushima and Niigata.

KEYWORDS: risk communication, risk communicator, dialogue

I. Introduction

This commentary is mainly based on the report that the Tokyo Electric Power Company (TEPCO) submitted at a seminar on risk communication in the nuclear sector that was held in August 2014 by the Human-Machine Systems Research Subcommittee of the Atomic Energy Society of Japan (AESJ). It features the risk communication activities pursued by TEPCO as part of its efforts to heed the lessons learned from the Fukushima Daiichi Nuclear Accident. To promote further discussion on risk communication from a diverse range of perspectives, this commentary also presents the challenges identified by TEPCO in its capacity as the entity responsible for the accident as well as a regular company.

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Previous commentary
(1) Why scientists should get involved (https://doi.org/10.3327/jaesjb.57.9_583) (in Japanese)

II. Lessons Learned from the Fukushima Daiichi Nuclear Accident [1)]

In September 2012, TEPCO established the Nuclear Reform Special Task Force to analyze both the technical and organizational factors behind the Fukushima Daiichi Nuclear Accident under the oversight of the Nuclear Reform Monitoring Committee. The root cause identified by the task force was inadequate preparedness against accidents due to excessive confidence in existing safety measures and the priorities assigned to the capacity factor and other business performance indicators. The accident cannot be ascribed to a natural disaster. Rather, intellectual efforts were not sufficiently exhausted to prepare against avoidable accidents. Taking this failure to heart, the task force looked deeper into the safety mindset, technical competence, and communication skills as factors behind the accident.

A deeper analysis of inadequate preparedness as a root cause in terms of communication skills revealed a hesitancy before the accident to share information on residual risks and communicate in general with the local communities. As shown in **Figure 1**, for example, any acknowledgement of the need for severe accident measures was assumed to weaken the argument that nuclear power plants were already safe enough.

III. Reform Plan for Enhancing Nuclear Safety [1)]

The six measures listed below have been adopted to radically address problems associated with the equipment at nuclear power plants (hardware measures) and substantially address organizational problems (intangible measures).

Measure 1: Reform of management
Measure 2: Monitoring of management and reinforced support
Measure 3: Reinforcement of capacity to develop defence in depth proposals
Measure 4: Enhancement of risk communication
Measure 5: Reorganization of power plants and headquarters in the event of an emergency
Measure 6: Organizational overhaul of power plants during normal operations and reinforcement of technical competency for operations by TEPCO employees only

Of these six measures, this commentary will focus on Measure 4 to enhance risk communication.

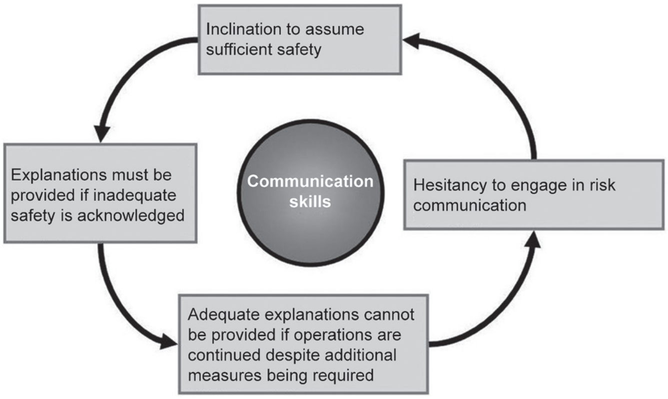

Figure 1 Vicious cycle (communication skills)

IV. Fulfillment of Risk Communication

Multiple layers of defence in depth must be built up to reduce the residual risks to a socially acceptable level. An additional measure will need to be adopted to eliminate the assumption that an announcement of risks would lead to the regulatory authorities and local communities demanding excessive measures, leaving the utility companies with no option but to shut down their nuclear reactors. If this kind of brain freezing due to above assumption actually happened, new countermeasures will also be needed to dissolve the assumption for future. Accordingly, TEPCO shifted its policy to the pursuit of risk communication. Based on the idea that there is no such thing as absolute safety, leaders of the nuclear sector are now expected to disclose any risks directly and seek an understanding of their safety measures from the local communities and the wider society.

As the entity responsible for the Fukushima Daiichi Nuclear Accident, TEPCO assumes responsibility for disclosing any risks and the corresponding countermeasures to the public. It must also accurately communicate the risks of nuclear emergencies while at the same time sincerely acknowledging and addressing any questions and concerns that the public may have. Such communication would enable TEPCO to obtain useful information about unnoticed risks as well as develop a shared understanding of a socially acceptable level of risks and a means of addressing the risks of extremely rare events associated with grave consequences.

Accordingly, TEPCO has committed itself to risk communication with the goal of “disclosing risks, providing explanations and holding discussions on how to enhance nuclear safety with respect to these risks, and gaining a certain degree of public understanding of these measures.” To achieve this goal, confidence building amongst the local communities, TEPCO, and the wider society is considered essential.

1. Appointment of Risk Communicators

TEPCO has appointed professional risk communicators who provide close support to upper management and leaders in the nuclear sector to ensure that they always bear in mind the perspectives of the public. They help plan the methods by which risks are acknowledged and disclosed, explain any limitations, recommend policies, and conduct risk communication according to these policies. As of the end of April 2015, TEPCO has appointed a total of 37 risk communicators, with 11 assigned to its Tokyo headquarters, 13 to Fukushima (including the Daiichi and Daini Nuclear Power Plants), 11 to Niigata (including the Kashiwazaki-Kariwa Nuclear Power Plant), and 2 to Aomori (including the construction site of the Higashidori Nuclear Power Plant).

The upper management and leaders in the nuclear sector always seek the opinions of risk communicators before making any major business decisions. These executives also consciously encourage the relevant units inside TEPCO to carry out any recommendations made by the risk communicators that incorporate requests from the local communities, the wider society, and the regulatory authorities.

Aside from the practice of holding daily dialogues, the risk communicators undergo training programs conducted by external lecturers with the aim of gaining further skills for engaging in risk communication with the local communities and the broader society.

2. Creation of a Social Communication Office

The Nuclear Power Department and TEPCO as a whole used to consider it best to "smooth things over." This conduct fell short of public expectations. They communicated without giving much thought to the information that they were sharing with the public. The company was even unable to recognize that its insincere response to members of the Diet Accident Investigation Committee was an issue of concern for the public. Without reform, an organizational culture such as this would obstruct proper information sharing on risks and render risk communicators useless.

Sincere communication with society regarding the risks associated with nuclear energy is crucially dependent on the urgent and daring reform of this organizational culture. After much soul-searching over its earlier failure to get to the crux of this deviant culture, TEPCO has now decided to invite an external expert to swiftly and effectively realign the company with society and pursue more socially minded risk communication.

This external expert was appointed as the director of the new Social Communication Office, which reports directly to the president. The office employs 15 full-time personnel, including the director and vice director. As indicated by the organizational structure shown in **Figure 2**, the office pursues robust risk management and conducts awareness activities concerning the expectations and perspectives of the public. Organizational reform is initially being pursued with the Nuclear Power Department. The office has been assigned the roles described below.

- Conducting of in-house awareness activities: Mobilize risk communicators to collect detailed information on the risks involved in nuclear power operations and conduct awareness activities regarding the importance of sensitivity to the sentiments of the local communities and the wider society.
- Collection of information related to the activity status and improvement instructions: Analyze the collected risk information and issue instructions concerning the necessary countermeasures for potential and imminent risks while keeping in mind public expactations and consensus.
- In-house sharing of case studies of improvement instructions: Share instructions widely within the company to improve its corporate culture and company-wide risk management.

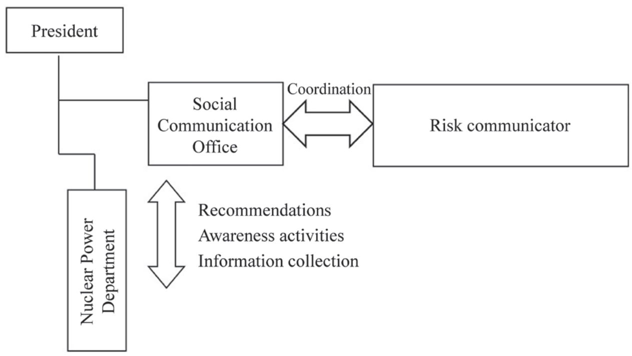

Figure 2 Organizational structure for promoting risk communication (as of May 2015)

V. Case Examples of Risk Communication in Fukushima

1. Dealing with Difficult Announcements Regarding the Fukushima Daiichi Nuclear Power Plant

In 2013, TEPCO became mired in a problem associated with how the spilling of contaminated water into the port at the power plant was announced. From that point on, the Social Communication Office shifted its basic policy and took all possible efforts to address matters that were of concern and interest to the local communities and the wider society [1]. Under this new policy, the office would—without considering the possible public repercussions—swiftly and honestly announce the risks and worst-case scenarios expected based on the assessment results even without clear and sufficient supporting evidence.

After this policy shift, the next issue to be addressed was how to respond to the public interest in the question of how much radioactive material had been released. The earlier approach would have prompted the company to announce something like the following: "An assessment is impossible due to the insufficient amount of data that is available at the moment." Instead, the Social Communication Office and the Nuclear Power Department conducted assessments based on confirmed data at that time to make the following series of announcements [1].

- Case Study 1 (August 2, 2013): Estimated spill into the port of contaminated ground water containing about 10 to 40 TBq of tritium.
- Case Study 2 (August 21, 2013): Estimated spill into the port of contaminated water containing up to 30 TBq of strontium-90 and cesium-137 from the trenches of Units 2 and 3.

Purely in terms of risk communication [2-5], these announcements should have been combined with communication regarding risk assessments with due consideration given to the relevant implications and interpretations as well as risk management with due consideration given to the necessary countermeasures. At that moment, the swiftness and transparency of the announcements were probably prioritized in light of the high public interest in the latest status of the power plant.

2. Attentive Dialogues with Residents of Fukushima Prefecture

Residents of Fukushima Prefecture frequently express the need for a clear explanation of how TEPCO is handling decommissioning work and contaminated water. Such requests are shared within the company and they now weigh heavily on the continuing dialogues with these residents. Employees visit the residents' temporary shelters and upper management is trying to establish more opportunities to provide the necessary explanations. Three specific activities are described below to provide examples.

- TEPCO managers provided explanations at prefectural meetings [6] organized by the prefectural government to discuss the safe decommissioning of the nuclear power plants in Fukushima and at council meetings [7] organized by the Ministry of Economy, Trade and Industry to discuss decommissioning and measures against contaminated water in Fukushima (17 times in total by the end of April 2015).
- TEPCO employees visited a total of about 150 temporary shelters and other such places to explain the progress that had been made in terms of the Mid-and-Long-Term Roadmap.
- Brochures were inserted into information bulletins issued by the municipalities to provide updates on the Fukushima Daiichi Nuclear Power Plant (once a month in nine municipalities).

3. Greater Opportunities for Site Visit

Another request that residents from the prefecture frequently make is for them to have more opportunities to see and confirm the current situation at the plant for themselves. In 2013, the number of visitors had to be limited to ensure their safety in the on-site environment with due consideration given to the work that needed to be carried out there. Respecting the residents' wishes, TEPCO is trying to host more visitors by making the following improvements.

- Regular bus services have been organized exclusively to host large numbers of visitors from Japan and abroad (shared by multiple groups invited to visit the site from inside the buses).
- The hosting capacity was increased so that more regular bus services could be offered and more visitors could be invited to attend the site visit.
- Revision of briefing materials for the site visit and information materials on decommissioning were provided to improve visitor satisfaction.

Following this increase to the hosting capacity, 9,207 visitors attended a total of 770 site visits organized from April 1, 2013, to March 31, 2015.

In addition, a video tour has been posted on the official TEPCO website so that people can ascertain the situation at the power plant visually and virtually [1].

VI. Case Examples of Risk Communication in Niigata

1. Dialogues with Citizens (Case Study 1: Briefing Sessions for Local Communities)

Briefing sessions are organized for the local communities located in the vicinity of power plants to explain the decommissioning activities being conducted at the Fukushima Daiichi Nuclear Power Plant, the safety measures being implemented at the Kashiwazaki-Kariwa Nuclear Power Plant, and so forth.

Briefing sessions have been conducted since October 2007 in each local community located in Kashiwazaki and Kariwa. After the Fukushima Daiichi Nuclear Accident, 18 sessions were conducted in each community up to the end of April 2015.

2. Dialogues with Citizens (Case Study 2: Community Meetings)

TEPCO also participates in monthly community meetings with community representatives to address any doubts, questions, and requests that they may have to ensure transparency on nuclear power plants.

The community meeting is officially called as the Communal Committee for Ensuring Transparency on Kashiwazaki-Kariwa Nuclear Power Plant. The preparatory meeting to establish the committee was held in 2002. Since then, a total of 143 regular meetings have been held up to the end of April 2015. The committee consists of up to 25 members recommended by various groups that are recognized by the Committee, who are residents in Kashiwazaki and Kariwa, as the local communities.

Committee members are given the following five assignments:

(1) Examine and monitor the operations of the nuclear power plant and its impact
(2) Make recommendations to the power utility company and other stakeholders
(3) Share information with residents regarding their discussions at meetings and other

activities

(4) Conduct training for committee members

(5) Carry out any other tasks that are necessary to achieve the goals of the Committee

3. Greater Capacity to Host Site Visit at the Kashiwazaki-Kariwa Nuclear Power Plant

TEPCO believes that it is best to allow people to see the safety measures in place so that they can convince themselves of the safety of nuclear power. Accordingly, the company organizes tours while building up its capacity to host visitors. In fiscal 2014, the plant hosted 14,275 site visitors.

VII. Summary of Issues Ahead

TEPCO recognizes that the following issues will need to be addressed to enhance risk communication going forward.

- How we should switch to risk communication that is mainly aimed at rebuilding trust?
- How we should coordinate internal communication and external risk communication to cultivate social sensitivity throughout the organization?
- How we should incorporate any opinions and questions that we encounter during risk communication into the PDCA (plan, do, check, and action) cycle in the risk management that we conduct?

Meanwhile, external experts acquainted with such matters have shared the following opinions regarding risk communication by TEPCO.

- Is risk communication viable in Fukushima? In practice, communication may be taking place between the victims and the party at fault.
- The mistrust toward nuclear energy that we observe today may be rooted in mistrust toward the people and organizations that handle nuclear technologies rather than the technologies themselves.
- External communication should be preceded by internal communication.

The pursuit of ever better dialogue through risk communication is a road with no end. TEPCO has simply taken its first step down this road. The company intends to continue holding dialogues with the aim of gradually fostering the seeds of trust.

VIII. Conclusions

In August 2014, the content of this commentary was presented at a seminar on risk communication in the nuclear sector. The participants shared the following comments.

- It is important to listen to the public attentively in addition to sharing information with them.
- Care must be taken to avoid figures shared in a briefing or a dialogue from taking on a life on their own.

Exchanging lessons learned and challenges encountered in risk communication with forerunners across the borders of companies and organizations provided an excellent opportunity for TEPCO to reflect on its earlier activities. We are grateful to both the participants and the organizer of the seminar for this precious opportunity.

Some international organizations have evaluated the risk communication that TEPCO has conducted to date as follows.

- In a mission report [8], the International Atomic Energy Agency (IAEA) appreciated the establishment of the Social Communication Office and other measures aimed at building up our organizational capacity.
- TEPCO applied to the Public Information Material Exchange (PIME) organized by the European Nuclear Society [9] and received a communication award.

TEPCO will continue to seek improvements by actively collaborating with other organizations and external experts while incorporating their feedback.

Regrettably, despite the ongoing efforts described above, it was revealed in February 2015 that radioactive concentration measurements from drainage canal at the Fukushima Daiichi plant had not been announced for almost ten months [1]. TEPCO deeply apologizes for having undermined confidence in its commitment to disclosure. The company has undertaken measures such as preventing the contamination of rainwater, deploying purification materials to the drainage system, and redirecting the drainage to the port. We have examined the risks exhaustively from the perspective of local community members and the wider society. As part of its endeavors to regain society's trust, TEPCO is seeking to improve the way that it shares information while attentively listening to the views of the public by taking heed of one of the comments made in this seminar.

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Lessons Learned from Great East Japan Earthquake Disaster

−From Report on the Great East Japan Earthquake Disaster; Mechanical Engineering Volume−

Japan Atomic Energy Agency, **Yasuo Koizumi**

This commentary mainly discusses the recommendations compiled by the JSME Research and Recommendation Committee on the Great East Japan Earthquake Disaster (chair: Professor Masaki Shiratori of Yokohama National University) in the Mechanical Engineering Volume of a committee report as well as the recommendations made by Working Group 5 of the committee regarding damage to energy infrastructure. The former recommendations are divided into the following categories: large-scale system integration; approach to design basis and beyond design basis; challenges in risk communication; and continuous investigation and development of codes and standards. Working Group 5 has produced ten recommendations, such as addressing the technical challenges encountered at nuclear facilities and creating a future energy society.

KEYWORDS: Great East Japan Earthquake Disaster Report, proposal, mechanical engineering, large-scale system integration technology, beyond design basis, risk communication

I. Introduction

The Great East Japan earthquake and tsunami that were generated off the Pacific coast of Tohoku on March 11, 2011, caused what is now referred to as the Great East Japan Earthquake Disaster. The entire eastern half of Japan was affected by the disaster, leaving many people dead or missing. It even triggered an accident at a nuclear power plant. It is no exaggeration to say that the disaster was on an unprecedented scale that had never been seen before in the recorded history of Japan. In the immediate aftermath of the earthquake, the Japan Society of Mechanical Engineers (JSME) set up a taskforce under the leadership of Professor Yoichiro Matsumoto, the 88th president of the society. The taskforce was composed of the Research and Recommendation Committee on the Great East Japan Earthquake Disaster, which was chaired by Professor Masaki Shiratori of Yokohama National University, and another Committee on the Recommendations from a Long-term Perspective, which was chaired by Professor Shigehiko Kaneko of the University of Tokyo. These committees mainly investigated

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the damage left in the wake of the disaster from the viewpoint of mechanical engineering. With the aim of creating a more robust society, they also examined matters that engineers and researchers in the field of mechanical engineering need to reflect on, lessons that they should learn, areas that will need to be improved in the future, and positive roles that the JSME can play. The Research and Recommendation Committee on the Great East Japan Earthquake Disaster involved as a part of eight academic societies in its joint investigation. These societies were the Japanese Geotechnical Society, the Japan Society of Civil Engineers, JSME, the Architectural Institute of Japan, the Atomic Energy Society of Japan, the Seismological Society of Japan, the Japan Association for Earthquake Engineering, and the City Planning Institute of Japan. The outcomes have been compiled in the *Report on the Great East Japan Earthquake Disaster—Mechanical Engineering Volume* [1). Yasuo Koizumi, the author of this commentary, participated in these investigations as a committee member and the chair of one of the eight working groups formed under the committee (Working Group 5 on damage to energy infrastructure). This commentary discusses the recommendations compiled in the report and other recommendations made by Working Group 5.

II. Recommendations Made by the JSME Research and Recommendation Committee on the Great East Japan Earthquake Disaster

1. Committee Structure and Activities

Consisting of ten members (including the author) and four observers, the research committee chaired by Professor Shiratori established the following eight working groups.

Working Group 0: Characteristics of the Earthquake and Tsunami—chaired by Kojiro Irikura (Aichi Institute of Technology)
Working Group 1: Damage to Machines and Equipment and Good Practices for Seismic Countermeasures—chaired by Professor Satoshi Fujita (Tokyo Denki University)
Working Group 2: Understanding the Mechanism of Tsunami-induced Damage to Machines and Structures Based on Mechanical Analysis—chaired by Professor Shinobu Yoshimura (University of Tokyo)
Working Group 3: Challenge of Robot Technologies at the Disaster Sites—chaired by Professor Hisashi Ohsumi (Chuo University)
Working Group 4: Analysis of Traffic and Physical Distribution Systems in Areas Affected by the Disaster—chaired by Professor Takayoshi Kamada (Tokyo University of Agriculture and Technology)
Working Group 5: Damage to Energy Infrastructure—chaired by Yasuo Koizumi (Shinshu University)
Working Group 6: Nuclear Codes and Standards and Future Perspective—chaired by Professor Masaki Morishita (Japan Atomic Energy Agency)
Working Group 7: Crisis Management in Earthquakes, Nuclear Accidents, and Other Events—chaired by Keiji Kondo (Fukuda & Kondo Law Office)

The various investigations were conducted by the respective working groups over the course of two years with the aim of, for instance, assessing the damage, considering scenarios for reconstruction, and ensuring better preparedness for crisis management. Rather than being fixated on the extent of damage, these investigations adopted basic principles aimed at proactively identifying good practices for crisis management that would mitigate damage. Issues related to nuclear power plants and other such matters were carefully divided into categories. In addition, the various types of damage were sorted according to whether they were caused by seismic forces or the tsunami.

Reports and recommendations from the respective working groups were, after due peer review and coordination, compiled in the *Report on the Great East Japan Earthquake Disaster—Mechanical Engineering Volume*.

2. Recommendations for Mechanical Engineering Based on Lessons Learned from the Last Earthquake-Induced Disaster

The damage wrought by the disaster was so enormous and extensive that it needed to be covered in a wide range of reports. The committee considered what types of recommendations should be presented to society as well as what lessons engineers and researchers of mechanical engineering should learn from the disaster. As chair of the committee, Prof. Shiratori led the process of extracting recommendations from a broad range of perspectives.

The findings were summarized in "Recommendations for Mechanical Engineering Based on Lessons Learned from the Great East Japan Earthquake" as follows:

(1) Large-scale system integration
(2) Approach to design basis and beyond design basis
(3) Challenges in risk communication
(4) Continuous investigations and development of codes and standards

(1) Large-scale system integration

A large-scale system for a nuclear power facility or the like integrates knowledge from a wide range of science and engineering fields to constitute the system. However, this system has proven to be beset by vulnerabilities associated with gaps among the various different types of expertise when it is exposed to an earthquake, a tsunami, or another major disaster. These vulnerabilities must be addressed by establishing a methodology for system integration to examine the overall picture of the system, identify the weak spots hidden within the gaps among the various different types of expertise, and implement the necessary measures. The JSME also recommends its own society-wide initiatives in an effort to systematize a "science of design."

Researchers who engage in cutting-edge research at universities and the like tend to be interested in the "science of recognition" within their narrowly segmented fields. They have neglected efforts to systematize a "science of design" aimed at integrating the knowledge that they obtain from their research. The outcomes obtained from cutting-edge research in a science of recognition are supposed to be incorporated into patents, codes, and standards for practical application in society. In reality, however, the researchers seem to be content with just publishing their papers.

System integration is commonly conducted at a company's manufacturing sites to accumulate empirical knowledge in relation to design, manufacturing, operations, and so forth. Although sufficient information can be accumulated with respect to cars, electronic devices, and other mass-produced products, it is an unfortunate fact that little integration has taken place with respect to nuclear power generation, the space industry, and the development of other large-scale systems employed in society.

System integration is required from the moment a project is launched to develop a large-scale system. A team of experts from various fields is assembled to conduct the necessary integration on various levels, from the individual level through to the global level.

(2) Approach to design basis and beyond design basis

An artificial object can be designed only after the required specifications, including the maximum external force that the intended object is expected to endure over its service life, have been determined. If an external force from an earthquake, tsunami, or other major natural disaster may exceed this postulated limit, the following two questions need to be addressed.

(1) How should the postulated limit (safety goal) be determined?
(2) How should an event exceeding the postulated limit (i.e., beyond design basis) be dealt with?

The last earthquake disaster taught us the need to provide explanations for any safety goals that form the basis for a postulated limit and the risks of emergencies that may exceed this limit to ensure that society regards the risks as acceptable. Such a procedure is recommended for any postulated limit, and it should be applied not only to nuclear facilities, but also to chemical plants, railway systems, and other large-scale systems.

A postulated limit is commonly called a design basis. Any such value that involves safety is also called a safety goal. Postulated limits used to be determined based on discussions held by advisory boards of experts. However, these experts failed to help the public gain a clear understanding of their complicated and technical discussions. Prior to the assignment of any postulated limit, explanations must be provided regarding the safety goals that form its basis and the risks of emergencies that may exceed this limit to ensure that society regards the risks as acceptable.

Such a procedure should be taken not only with nuclear facilities, but also with chemical plants, railway systems, and other large-scale systems.

It is also important to obtain public consensus on the definition of damage that exceeds the socially acceptable limit, and this should be accompanied by discussions and preparations regarding the technical means required to support the necessary measures. The last earthquake-induced disaster revealed not only a failure to give due consideration to the possibility that damage to a nuclear power plant may exceed the socially acceptable limit, but also a failure to implement the necessary measures. Artificial objects usually carry risks, and proper management of residual risks is required. The principle of zero disasters is not viable.

With respect to mechanical safety education, Umezaki [2)] points out the following: “In Japan, a reduction in the incidence of industrial accidents is typically sought by enhancing the reliability of machines and improving education and training for workers. By nature, however, people make mistakes and machines experience failures and other such problems. Measures must be taken based on the assumption that these problems do take place. To this end, fool-proof and fail-safe designs as well as other safety technologies have an essential role to play.” Umezaki goes on to say, “Safety in Japan has been pursued by adopting measures based on the principle of zero disasters with no tolerance for industrial accidents. In contrast, the West has advanced the concept of risks by conceding that absolute safety cannot be achieved. Rather than insisting on the supposed notion of zero disasters by assuming no risks, it seems more important to clarify residual risks, provide users with the appropriate information, and clarify measures for managing residual risks (e.g., building safety management systems, establishing work procedures, conducting education and training, and using protective gear)." This reasoning embodies the approach associated with design basis and beyond design basis.

(3) Challenges in risk communication

In the design phase for any artificial object, the engineers and researchers involved in its manufacture need to predict the expected benefits and associated risks accurately, communicate them to the public, and obtain public acceptance. To do this, they must acquire two types of skills: the ability to accurately predict and manage risks (risk management) and the ability to communicate risks accurately to obtain public acceptance (risk communication). These qualities are expected of not only the individual engineers and researchers, but also the relevant universities, companies, governments, and other organizations. It is also recommended that the JSME earnestly engages in risk communication/management, and build and implement a system for delivering the necessary information to the public in a timely fashion to obtain public understanding.

With science and technologies advancing into ever more extensive areas, it has become almost impossible for the public to understand them accurately. People accept the black box of science and technologies to enjoy the benefits that they offer. Nonetheless, there are postulated limits and safety goals for each artificial object. It is quite difficult to explain this fact to the public and obtain their understanding. For this reason, the public tends to lose trust in engineers and researchers whenever trouble arises.

Experts need to obtain public understanding by providing the public with scientifically supported information. This task is needed to allow citizens to make the right choices regarding the possible resumption of nuclear power and future energy sources.

People expect both guaranteed safety and use at ease at all times. However, these two things do not go hand in hand. It needs to be clearly explained that there are always postulated values and limits to safety and that the possibilities of accidents that exceed these limits can never be excluded. The public must be properly informed of the safety limits (risks) of artificial objects as well as their benefits. To this end, the following two skills need to be acquired.

1. The ability to accurately predict and manage risks (risk management)
2. The ability to communicate risks accurately to obtain public acceptance (risk communication)

The methodologies used for risk management include probabilistic risk assessments.

Science communication skills must be acquired to ensure proper risk communication on engineering issues. The JSME and other expert groups should communicate their opinions on any new technical challenges that may have social repercussions after reaching agreement through careful discussions.

(4) Continuous investigations and development of codes and standards

The JSME will reinforce its partnership with the industrial and academic communities to apply the lessons learned from the Great East Japan Earthquake Disaster and mitigate the impact of any future massive earthquakes or other such disasters. Through this partnership, the findings from investigation and other research will be compiled to produce codes, standards, manuals, and so forth. The recommendations made by each of the working groups should be implemented with sincerity. To pass on the lessons learned from the last earthquake-induced disaster, the JSME also recommends human resource development, education, and training for junior researchers and engineers.

The more society matures, the more its citizens must shift their mindsets to engage more proactively in the process used to establish the codes and standards that concern them. Since the Meiji Restoration, the Japanese government has led the application of the codes and standards that they have established. For this reason, people today still expect someone else to prepare the codes and standards, and they feel content to follow the rules established by others. Such a mindset must be cast aside. An environment that is conducive for industry stakeholders to participate proactively in the process of creating codes and standards should be prepared so that they can give back what they output. Such an environment will also cultivate fertile ground for public trust in technologies.

III. Recommendations Made by Working Group 5 on Damage to Energy Infrastructure

1. Activities by Working Group 5

Working Group 5 has already published an interim report on their activities [3]. This commentary mainly presents the recommendations that were compiled thereafter.

The Pacific coast of Japan, which stretches from the Kanto region to the Tohoku region, is a major source of power that is generated by many thermal and nuclear power plants. Regardless of their type, these power plants were severely affected by the 2011 Great East Japan earthquake and tsunami. However, studies have revealed the robustness of thermal power plants and the vulnerability of nuclear power plants. Damaged thermal power plants were swiftly repaired to resume power transmission, so power shortages lasted much less time than was initially feared. Even the Haramachi Thermal Power Plant resumed its supply of power just one year and eight months after being devastated during the disaster.

Today's thermal power generation draws from the improvements that James Watt made to steam engines and the subsequent advancements in the technology to convert heat into mechanical energy. Initially, steam engines relied on a vacuum. Following the natural course of events, however, greater efficiency was pursued by using high-pressure engines despite strong resistance from James Watt. Larger boilers that made use of increasing amounts of pressure took a heavy toll, though. In around 1900, the United States recorded 300 to 400 boiler explosion accidents a year that resulted in up to about 10,000 injuries and about 1,000 deaths. To address this problem, the American Society of Mechanical Engineers created the Boiler & Pressure Vessel Code. The introduction of third-party inspections significantly reduced the incidence of boiler explosion accidents. This means, then, that thermal power technology took

200 years to mature and achieve its current level of robustness.

Commercial nuclear power generation began in Japan only about 50 years ago. Given this, it is safe to say that this technology still needs to mature over a much longer timeframe. It is, of course, extremely unfortunate that many people have been affected by accidents at nuclear power plants. Nevertheless, if we view this from the perspective of the history of technical advancements, nuclear power generation technology seems to have matured considerably over this short amount of time. This progress may have caused harm and people tend to focus on the vulnerability of nuclear power technology, but technical advancements take time and unfortunate events may happen along the way. However, technical maturity should also be sought by learning from such experiences. All of the members of Working Group 5 were united in their pursuit of a more robust and safe technology through necessary improvements, development activities, and countermeasures by heeding the lessons learned from the last disaster.

Historically speaking, the Japanese archipelago has been hit by massive earthquakes and tsunamis on a regular basis. Despite this, the Japanese people have built a nation on these islands, which are now home to almost 120 million people, including over 10 million people living in a single megacity. Unfortunately, memories of these natural disasters cannot be easily perpetuated as they strike Japan every few generations. Their national traits did not help either. In relation to education and training too, all of the members of Working Group 5 perceived the need to ensure physical and mental preparedness by leaving records, passing on stories, and regularly remembering the disasters of the past.

2. Recommendations Made by Working Group 5

Against this background, Working Group 5 has developed recommendations on the following ten issues.

(a) Technical issues at nuclear facilities
(b) Operational issues at nuclear facilities
(c) Social responsibilities of engineers, managers, and governments with respect to nuclear facilities
(d) Issues involving thermal power plants
(e) Lessons learned from the Great Hanshin Earthquake of 1995 that can be applied for energy systems
(f) Importance of preparedness through mitigative measures taken with energy systems
(g) Need for diversified energy sources
(h) Important perspectives for discussing energy policies
(i) Social impact of structural shifts in energy supplies and roles of engineers
(j) Building a future energy society

Due to space limitations, explanations will be provided for only some of these issues, not all of them. For more details, please refer to reference material [1)].

(1) Technical issues at nuclear facilities

Important lessons can be drawn from the construction work that was carried out back then to raise the height of the protection wall (by between 1.6 m and 2.8 m) for the seawater pumps at the Tokai No. 2 Nuclear Power Plant. The motors of the seawater pumps for cooling the emergency diesel generators avoided flooding by the tsunami in the part of the levee where holes had already been covered, but the motors of the other cooling seawater pumps were flooded in the part where holes had not been covered. Furthermore, gas turbines located on the roof of the important quakeproof building proved effective in supplying emergency power. These experiences suggest that sensible safety measures can technically deal well with flooding from a tsunami.

(2) Social responsibilities of engineers, managers, and governments with respect to nuclear facilities

Engineers and managers involved in electric power generation bear a social responsibility to modify the systems and operational methods for providing a vast amount of energy while always paying attention to state-of-the-art technologies. It is essential to recruit personnel who can make judgments based on the overall perspective and to organize practical education and training programs to build up this capacity among personnel on a steady basis.

(3) Lessons learned from the Great Hanshin Earthquake of 1995 that can be applied for energy systems

The Great Hanshin Earthquake of 1995, which struck directly beneath a metropolitan area, prompted a revision of Japan's technical standards. Despite the extensive damage that was caused across East Japan by the 2011 Great East Japan earthquake, which had a magnitude of 9.0, the proportion of transmission and substation facilities that suffered damage was definitely less than that from the Great Hanshin Earthquake. This achievement demonstrates how important it is to dutifully apply the lessons of the past and implement the necessary measures.

(4) Need for diversified energy sources

Unfortunately, as a land that is prone to natural disasters, Japan must secure energy sources for both regular use and emergency use. Electric power is one of the most important utilities, and the last tsunami taught us the importance of building up port facilities that can supply power from vessels to land as well as the development of onshore facilities with standalone power generators. In addition to disaster management, due consideration should be given to securing fuel supply chains and storage as well as easing the relevant regulations and implementing the necessary ordinances in places. One example of this is the easing of restrictions under the Fire Service Act on the storage capacity for fuels used to generate power at core evacuation facilities in areas affected by disasters. Indeed, the recovery of the gas supply in Sendai in just one month owes greatly to the main gas pipeline from Niigata to Sendai. Such infrastructure should be put in place throughout Japan.

(5) Social impact of structural shifts in energy supplies and roles of engineers

A hasty all-out transition from nuclear energy to thermal power and renewable energy sources would probably have many serious consequences for future Japan. Rising fuel costs would push up power generation costs. Furthermore, the production capacity of Japanese companies might be depressed by power shortages, which could further speed up the offshoring of their operations. People would find it harder to live with fewer employment opportunities and lower incomes, and it would be harder to fulfill the country's commitments to curbing global warming. In addition, Japan would not be able to make any technical contributions to emerging economies that need nuclear energy. In fact, the international community could cease to trust Japan on nuclear non-proliferation and other issues. Learned societies have an important mission to communicate these scientifically grounded arguments clearly to the public. The media and other entrusted organizations must understand their social role in communicating risk to the public and their responsibility to disclose accurate information and serve as a bridge between engineers and the public.

(6) Building a future energy society

The method that Japan uses to source its electric power will have a significant impact on the future of this resource-scarce country, how its people live, and how its society will function. Sources of electric power should be determined after long, hard discussions have been conducted based on scientific findings and evidence. This decision must be unswayed by simple cost estimates and emotional arguments. These discussions should be made from multifaceted perspectives to address intricately intertwined issues (e.g., long-term energy security as well as the possible impact on industry, the economy, employment, society, people's lifestyles, and the fight against global warming). An optimal mixture of energy sources should be sought by clarifying the characteristics of nuclear, thermal, and other existing power generation systems and by properly promoting renewable energy. To this end, consideration must be given to both people's lifestyles and industrial growth while duly ensuring the safety of nuclear energy.

IV. Conclusions

This commentary mainly presents the recommendations compiled by the JSME Research and Recommendation Committee on the Great East Japan Earthquake Disaster (chair: Professor Masaki Shiratori of Yokohama National University) in the Mechanical Engineering Volume of the Report on the Great East Japan Earthquake Disaster as well as the recommendations made by Working Group 5 of the committee regarding damage to energy infrastructure. Japan is hit by massive earthquakes, tsunamis, and other natural disasters on a regular basis. Such experiences could not be passed on very easily, because they strike Japan every few generations. I hope that lessons will be drawn from the damage caused by the last earthquake-induced disaster, passed on to the next generation, and applied in practice to create a more robust society built on technologies.

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Introduction of the Public Opinion and Discussion How to Provide Information Concerning Nuclear Energy

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On August 11, 2015, the Sendai Nuclear Power Station became the first nuclear power station in Japan to resume full-fledged operations since the 2011 Tohoku earthquake (also known as the Great East Japan earthquake) and tsunami. It is high time that we begin to reconsider how society should deal with nuclear energy. This commentary begins by providing some background to this issue with reference to the results of a public opinion survey conducted by the Japan Atomic Energy Relations Organization with respect to the use of nuclear power. The latter half of this commentary discusses how information on nuclear and other energy sources should be shared.

KEYWORDS: Nuclear energy, public opinion survey, provision of information

I. Introduction

On August 11, 2015, the Sendai Nuclear Power Station became the first nuclear power station in Japan to resume full-fledged operations since the 2011 Tohoku earthquake and tsunami (hereinafter referred to as the "earthquake-induced disaster"). Nuclear energy has taken another step forward since its radical overhaul (i.e., fundamental reconsideration of its value, potential, risks, and necessity) was prompted by the earthquake-induced disaster.

The way society deals with nuclear energy had been discussed in relation to various aspects even before the disaster. However, the disaster almost completely discredited all that had been discussed and attempted earlier. Society has been compelled by the disaster to reconsider how we deal with nuclear energy. The resumed operation of this nuclear power plant should be considered a good opportunity for a radical overhaul.

This commentary begins by providing some background to this issue with reference to the results of a public opinion survey. The data was collected by the Japan Atomic Energy Relations Organization (JAERO) between October and November 2014 in their survey on the use of nuclear power. **Table 1** provides an outline of the survey.

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Table 1 Outline of the public opinion survey on the use of nuclear power

Target respondents:	Women and men aged between 15 and 79 who live in Japan
Method:	Omnibus questionnaires collected later from respondents assigned based on quota sampling
No. of responses:	1,200
Period:	October 31 to November 12, 2014

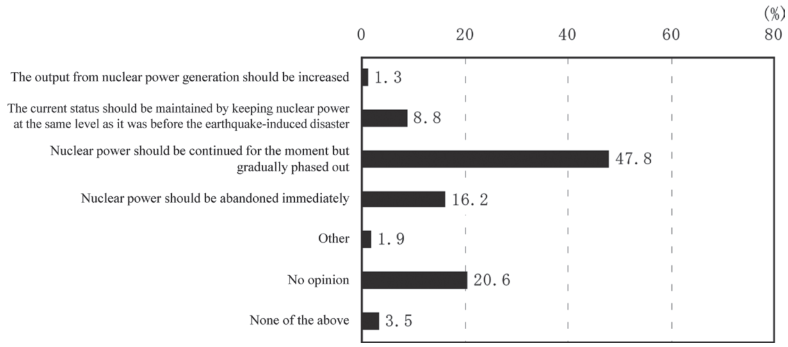


Figure 1 Cognition on the use of nuclear power
"Question 6: What should Japan do about the use of nuclear power in the future?"

II. Public Opinion on Nuclear Energy

This section briefly presents the results of the public opinion surveys with respect to the cognition on the use, the perceived benefits and perceived risks of nuclear power, respectively.

Due to space limitations, the role of trust as an important psychological factor in considering nuclear energy is not covered in this commentary. For details on this matter, please refer to the relevant discussions presented in a series of survey reports [1] published by JAERO (particularly the FY2013 issue).

1. Cognition on the Use of Nuclear Power

Figure 1 shows how people envision the future of nuclear power based on the results of the survey. Almost half of the respondents selected "Nuclear power should be continued for the moment but gradually phased out" as their response. In other words, although people would rather not rely on nuclear power in the future, they reluctantly accept the need to do so to meet today's needs. About 10% of the respondents selected "The output from nuclear power should be increased" or "The current status should be maintained by keeping nuclear power at the same level as it was before the earthquake-induced disaster." Slightly fewer than 20% selected "Nuclear power should be abandoned immediately," while another 20% had no opinion on the matter.

Earlier studies, such as the one quoted in *The Fukushima Nuclear Accident and Public Opinion* [2], often find that over half of the respondents want nuclear power to be abandoned. This is due to the binary options that they were given between the continued use of nuclear power or its abandonment. In this regard, the JAERO survey referred to in this commentary provides an interesting insight into the more nuanced opinions of people who are reluctant to make such binary choices.

2. Perceived Benefits of Nuclear Power

Figure 2 presents the perceived benefits of nuclear power from three different perspectives: its contribution to the national economy, its contribution to household budgets, and its contribution to efforts to curb carbon emissions. According to the results of this survey, people generally believe that the national economy can develop further without relying on nuclear energy, although this would mean higher electricity bills. A slight majority believe that nuclear power plays a positive role in curbing carbon emissions. Most probably, however, the proportion of people who share this perception has dropped significantly in comparison to the findings of earlier studies conducted before the disaster[3)].

Table 2 shows an interesting trend through the cross tabulation of the cognition on the use of nuclear power and its perceived benefits. In the row corresponding to calls for the immediate abandonment of nuclear power, two peaks (moderate responses and strongly negative responses) can be seen, particularly for responses related to household budgets and reductions in carbon emissions. Most probably, some respondents in favor of the immediate abandonment of nuclear power recognize its benefits while others do not recognize any such benefits at all. Further analysis based solely on this survey would be difficult. However, further detailed analysis and studies are necessary to consider the gaps in perceptions that still produce the same opinion in favor of the immediate abandonment of nuclear energy, as well as the processes that shape these perceptions.

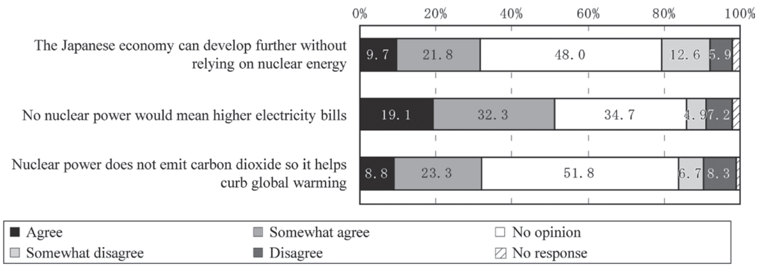


Figure 2 Perceived benefits of nuclear power
"Question 7: Do you agree with the following statements?" (Only relevant questions were quoted.)

Table 2 Cross tabulation of the perceived benefits and cognition on the use of nuclear power

	The Japanese economy can develop further without relying on nuclear energy					No nuclear power would mean higher electricity bills					Nuclear power does not emit carbon dioxide so it helps curb global warming				
	Yes	←		→	No	Yes	←		→	No	Yes	←		→	No
Total N=1,200	116 (9.7)	261 (21.8)	576 (48.0)	151 (12.6)	71 (5.9)	229 (19.1)	387 (32.3)	416 (34.7)	59 (4.9)	86 (7.2)	106 (8.8)	280 (23.3)	621 (51.8)	80 (6.7)	99 (8.3)
Increase output N=16	0 (0.0)	3 (18.8)	4 (25.0)	4 (25.0)	5 (31.3)	4 (25.0)	8 (50.0)	0 (0.0)	4 (25.0)	0 (0.0)	3 (18.8)	6 (37.5)	3 (18.8)	3 (18.8)	1 (6.3)
Maintain status before the accident N=105	0 (0.0)	9 (8.6)	44 (41.9)	38 (36.2)	13 (12.4)	31 (29.5)	37 (35.2)	31 (29.5)	4 (3.8)	1 (1.0)	19 (18.1)	33 (31.4)	47 (44.8)	6 (5.7)	0 (0.0)
Gradually phase out N=573	59 (10.3)	143 (25.0)	276 (48.2)	68 (11.9)	18 (3.1)	123 (21.5)	215 (37.5)	175 (30.5)	28 (4.9)	23 (4.0)	54 (9.4)	152 (26.5)	287 (50.1)	39 (6.8)	35 (6.1)
Abandon immediately N=194	52 (26.8)	60 (30.9)	55 (28.4)	8 (4.1)	13 (6.7)	26 (13.4)	54 (27.8)	51 (26.3)	16 (8.2)	45 (23.2)	11 (5.7)	39 (20.1)	74 (38.1)	17 (8.8)	52 (26.8)
No opinion N=247	2 (0.8)	35 (14.2)	169 (68.4)	23 (9.3)	15 (6.1)	31 (12.6)	62 (25.1)	133 (53.8)	5 (2.0)	10 (4.0)	10 (4.0)	35 (14.2)	180 (72.9)	14 (5.7)	5 (2.0)

The percentage indicated for each response within a given row appears in parentheses. The table does not include data for "Other" and "None of the above" in relation to "Cognition on the use of nuclear power" or data for "No response" in relation to "Perceived benefits of nuclear power." The "Increase output" category should be used for reference only given the small N value.

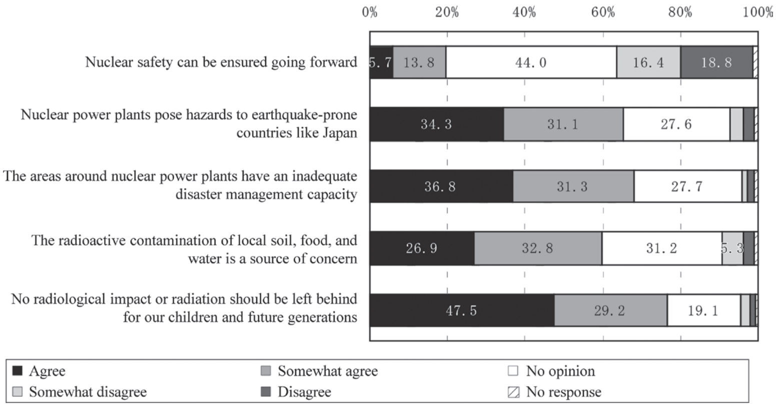


Figure 3 Perceived risks of nuclear power
"Question 7: Do you agree with the following statements?" (Only relevant questions were quoted.)

3. Perceived Risks of Nuclear Energy

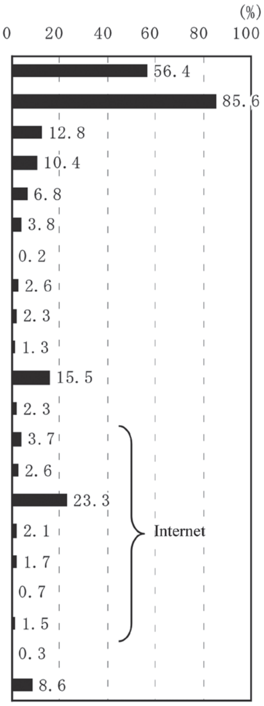
Figure 3 presents the perceived risks of nuclear energy from five different perspectives: nuclear safety, earthquake hazards, disaster management, the impact of radioactivity on the respondents themselves, and the impact of radioactivity on future generations. Broadly speaking, high levels of perceived risks can be noted in relation to every aspect of nuclear energy. The already high level of perceived risks associated with earthquakes before the disaster increased even further after the disaster [3]. Despite ongoing efforts to bolster the disaster management capacity, people still seem to think that is not enough.

Concerns over radioactive contamination and the impact of radiation remain. People tend to be more concerned about the impact on future generations than the impact on themselves. The disposal of high level radioactive waste is a major challenge associated with nuclear power. As pointed out in a study conducted by Tanaka (1998), the risks posed by high level radioactive waste are greater than those posed by the nuclear power plants themselves [4]. Given people's strong aversion to endangering future generations, the hurdle to be overcome with respect to the disposal of high level radioactive waste is growing ever higher.

III. How Information Should be Shared

Moving on to another subject, this section discusses how information should be appropriately shared among people as the basic premise for nuclear power to be continued going forward.

The first point to be considered is how people obtain information on nuclear and other energy sources. Many studies have found that people obtain information most commonly from television programs, followed by newspapers and then the Internet. With reference to **Figure 4**, the JAERO survey also found that people mostly seek information from television programs (85.6%) and newspapers (56.4%). As the survey broke down the Internet into different categories, it turned out that the third most popular source of information is news websites (23.3%) and that people do not obtain much information from other sources available over the Internet. This finding suggests that people obtain a considerable amount of information on nuclear and other energy sources through the mass media in one form or another, be it from



Source	(%)	Most socially minded N = 185	Moderately socially minded N = 482	Less socially minded N = 341	Least socially minded N = 192
Newspapers	56.4	150 (81.1)	315 (65.4)	153 (44.9)	59 (30.7)
Television programs	85.6	177 (95.7)	439 (91.1)	292 (85.6)	119 (62.0)
Radio programs	12.8	51 (27.6)	72 (14.9)	21 (6.2)	9 (4.7)
Magazines (weekly, monthly, etc.)	10.4	46 (24.9)	55 (11.4)	19 (5.6)	5 (2.6)
Municipal newspapers	6.8	35 (18.9)	34 (7.1)	9 (2.6)	4 (2.1)
Books and brochures	3.8	23 (12.4)	19 (3.9)	4 (1.2)	0 (0.0)
Videos and DVDs	0.2	0 (0.0)	2 (0.4)	0 (0.0)	0 (0.0)
Lecture meetings, briefing sessions, seminars, and similar events	2.6	14 (7.6)	14 (2.9)	1 (0.3)	2 (1.0)
School	2.3	4 (2.2)	10 (2.1)	9 (2.6)	4 (2.1)
Museums, exhibition centers, and public relations facilities	1.3	3 (1.6)	10 (2.1)	2 (0.6)	0 (0.0)
Conversations with family members, friends, and acquaintances	15.5	59 (31.9)	80 (16.6)	39 (11.4)	8 (4.2)
Circulated notices	2.3	12 (6.5)	11 (2.3)	4 (1.2)	1 (0.5)
National and local government websites (Internet)	3.7	18 (9.7)	19 (3.9)	6 (1.8)	1 (0.5)
Websites of nuclear power utilities, research institutes, etc. (Internet)	2.6	12 (6.5)	14 (2.9)	5 (1.5)	0 (0.0)
News websites (Internet)	23.3	46 (24.9)	139 (28.8)	71 (20.8)	23 (12.0)
Twitter (Internet)	2.1	4 (2.2)	13 (2.7)	7 (2.1)	1 (0.5)
Facebook (Internet)	1.7	5 (2.7)	7 (1.5)	7 (2.1)	1 (0.5)
E-newsletters and other emails (Internet)	0.7	2 (1.1)	2 (0.4)	3 (0.9)	1 (0.5)
Other information from the Internet (Internet)	1.5	5 (2.7)	10 (2.1)	2 (0.6)	1 (0.5)
Other	0.3	0 (0.0)	2 (0.4)	1 (0.3)	0 (0.0)
Nothing in particular/Not sure	8.6	0 (0.0)	13 (2.7)	28 (8.2)	62 (32.3)

Figure 4 Sources of information on nuclear and other energy sources
"Question 12: How do you usually obtain information on nuclear and other energy sources? (Please choose all applicable options.)"
Each option has been cross tabulated with the degrees of sociality indicated in the right-hand section. The percentage indicated for each response within a given column appears in parentheses. Refer to Table 3 for the classifications by degree of sociality.

television, newspapers, or the Internet.

So, what other sources do people get information from then? Conversations with family members, friends, and acquaintances ranked fourth (15.5%) as a source of information. Indeed, face-to-face conversations on nuclear and other energy sources play an important role that is second only to the mass media.

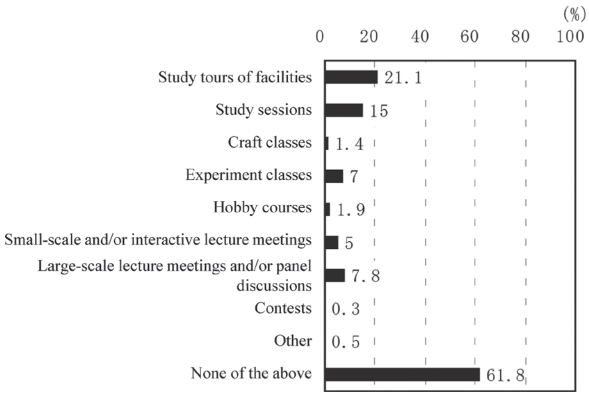
In the right-hand section of Figure 4, sources of information have been cross tabulated according to the degree of sociality of the respondents as classified according to the number of options selected from **Table 3**. In this context, "sociality" is used as an indicator of the weight of each respondent's commitment to society.

Regardless of their level of sociality, the respondents mostly rely on television programs and newspapers as their sources of information. Interestingly, a lower degree of sociality is accompanied by a sharp drop in the proportion of respondents who obtain information from newspapers. Over 30% of the least social group responded that they have no particular sources of information or that they were not sure how they obtained information. Next to television and newspapers, the most social group sought information from conversations with family members, friends, and acquaintances. It appears that people who value social commitment tend to place more weight on face-to-face conversations.

Figure 5 shows the varying degrees of interest that the respondents had in terms of participating in events related to nuclear and other energy sources. It is important to note that more than 60% of the respondents indicated that they were not interested in any of the given

Table 3 Indicators of sociality

1. The respondent is or has recently been involved in volunteer activities
2. The respondent has never volunteered, but would like to do so at the next opportunity
3. The respondent often participates in local events and festivals
4. The respondent aims to vote in every election
5. The respondent values close interactions with local community members
6. The respondent is proactively involved in activities conducted by neighborhood associations, parent-teacher associations, and the like
7. The respondent values efforts to keep the local area clean and beautiful
8. The respondent believes that everyone should be hospitable and courteously attentive to visitors and tourists
9. The respondent values local traditions and culture and is trying to pass them on to the next generation
10. The respondent joins forces with neighbors in crime prevention and environmental initiatives
11. The respondent is concerned about the declining sense of public morality among children and youngsters
12. The respondent believes that citizens should take the initiative without leaving all problems and challenges to the local government
13. The respondent pays attention to local affairs and tries to keep abreast of relevant information
14. The respondent believes in the importance of mutual assistance during emergencies as well as adequate preparedness and drills for citizens to make this possible
15. The respondent believes that local temples, shrines, and other cultural properties should be cherished as part of Japan's spiritual heritage
16. None of the above



Most socially minded N = 185	Moderately socially minded N = 482	Less socially minded N = 341	Least socially minded N = 192
60 (32.4)	129 (26.8)	55 (16.1)	9 (4.7)
59 (31.9)	90 (18.7)	26 (7.6)	5 (2.6)
4 (2.2)	8 (1.7)	5 (1.5)	0 (0.0)
25 (13.5)	47 (9.8)	12 (3.5)	0 (0.0)
5 (2.7)	11 (2.3)	7 (2.1)	0 (0.0)
29 (15.7)	23 (4.8)	7 (2.1)	1 (0.5)
38 (20.5)	43 (8.9)	10 (2.9)	3 (1.6)
1 (0.5)	1 (0.2)	1 (0.3)	0 (0.0)
2 (1.1)	2 (0.4)	0 (0.0)	2 (0.1)
65 (35.1)	254 (52.7)	247 (72.4)	176 (91.7)

Figure 5 Degree of interest in participating in events related to nuclear and other energy sources
"Question 15: Which of the following events related to nuclear and other energy sources would you like to participate in? (Please choose all applicable options.)"
Each option has been cross tabulated with the degrees of sociality indicated in the right-hand section. The percentage indicated for each response within a given column appears in parentheses. Refer to Table 3 for the classifications by degree of sociality.

options. Furthermore, over 90% of the least socially minded group responded in this way according to the cross tabulation with the degree of sociality shown in the right-hand section of Figure 5. On the contrary, this kind of response decreased with higher sociality. Moderately socially minded respondents showed a greater interest in participating in study tours at facilities, study sessions, and similar events. In addition to these events, the most socially minded respondents tended to be more eager to participate in events involving face-to-face exchanges, such as large-scale lecture meetings with panel discussions and small-scale interactive lecture meetings.

Each of the respondents was asked to choose all of the applicable options. Respondents who chose one or two options from Options 1 to 15 were classified as less socially minded, respondents who chose three to seven options were classified as moderately socially minded, respondents who chose eight to fifteen options were classified as the most socially minded, and respondents who chose Option 16 were classified as the least socially minded.

These findings indicate that only a certain group (i.e., the most socially minded people) would participate in any event that is organized to provide information. The question of what should be done with respect to uninterested people is often encountered in discussions of how information should be shared. According to the results of this survey, information can be delivered to less socially minded people almost exclusively through the mass media (mostly by television). (Although this commentary does not address this matter, the survey results also revealed that least socially minded people tend to have little interest in nuclear and other energy sources.)

The author believes that more serious thought must be given to how and what kind of information should be shared with the most socially minded people who value social commitment. These people obtain information from a diverse range of channels. Instead of depending solely on the mass media, they obtain a significant amount of information from conversations with family members, friends, and acquaintances. In addition, they eagerly participate in events that are intended to provide information on nuclear and other energy sources. Unfortunately, however, such information is not shared with these receptive people in a suitable manner. The first step that we need to take is to provide opportunities and hold events that allow receptive people to engage in face-to-face exchanges. Such occasions should be carefully upgraded to provide an environment that is more conducive to enabling the participants to think independently and shape their own opinions. We should not worry about what needs to be done after that until we move onto the next stage.

Recently, grassroots movements related to nuclear power and other energy sources have been gathering momentum. Nuclear experts, utility companies, and other stakeholders should perhaps start participating more proactively in these low-profile efforts. It could be an important first step in gaining a better understanding of how people view such matters and helping them to shape their own opinions.

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Tsunami Resistant Engineering for Nuclear Safety (No. 6)

−Promotion of Disaster Reduction Around Nuclear Facilities and Risk Communication−

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Central Research Institute of Electric Power Industry, **Hiroyuki Yamada**

Two level tsunami hazards were assigned to reflect tsunami sizes after the massive tsunami generated by the 2011 Tohoku earthquake devastated East Japan. Furthermore, measures for disaster management and reduction are planned, while discussions are to be held on reducing disasters around vital facilities in coastal areas. In areas around nuclear facilities, it is even more important for necessary measures to be prepared in anticipation of any facility-related accidents that may result from the devastation caused by a tsunami. To better manage and mitigate tsunami disasters in areas around nuclear facilities, it is vital for power utilities as well as the national and local governments to fulfill their assigned roles in a coordinated manner and work together with municipalities and local residents.

KEYWORDS: Nuclear safety, tsunami disaster reduction, Level-1 tsunami & Level-2 tsunami, risk communication

I. Tsunami Disaster Management and Reduction

1. Tangible and Intangible Measures Against Tsunamis

Tsunami disaster management has been planned in a comprehensive manner by combining tangible measures that rely on embankments and other protective structures with intangible measures that mainly involve alerts and evacuation. The reasons for this approach include the varying sizes of tsunamis as natural phenomena, their infrequent and localized nature, and the difficulty involved in predicting them. For instance, the tsunami caused by the 1896 Sanriku earthquake required the relocation of villagers from Toni, Iwate to an elevated settlement and the construction of a seawall in Taro. In Japan, public measures for tsunami disaster management are legally grounded in the Coast Act and the Basic Act on Disaster Management. The Coast Act forms the basis for the construction of embankments and other coastal protections by prefectural governments, while the Basic Act on Disaster Management forms

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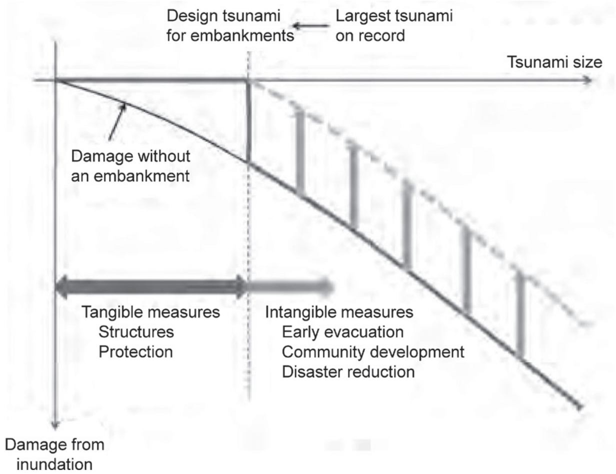

Figure 1 Schematic illustration of comprehensive tsunami disaster management

the basis for the development of local disaster management measures by municipalities. The major tsunami inundations that followed seismic events such as the 1993 Hokkaido earthquake and the 2004 Indian Ocean earthquake highlighted the importance of mutual assistance and self-help in addition to public assistance.

Figure 1 is a schematic illustration of the overall concept for a form of tsunami disaster management that employs a combination of tangible and intangible measures. The horizontal axis represents the tsunami height (size) and the vertical axis represents the increasing severity of damage in the negative direction. As shown in the figure, tangible measures are aimed at blocking the landward intrusion of seawater by using seawalls. They are designed by first envisaging the size of the target tsunami based on the largest tsunamis on record, while also giving due consideration to tidal and ocean waves. The damage that may be caused by a tsunami beyond the anticipated size is minimized by the adoption of intangible measures centered on early evacuation. This is the overall principle of tsunami disaster management. Many scientists and engineers have jointly investigated the tsunami triggered by the 2011 Tohoku earthquake. They have obtained data that will prove valuable in implementing the necessary measures against tsunamis in the future. Their analyses have highlighted the importance of intangible measures based on specific assumptions. They are also working to clarify the effectiveness and limits of tangible measures.

2. Two Anticipated Sizes of Tsunamis

Protective structures alone have limited efficacy in countering the massive tsunamis that occur once every several centuries or even less frequently. The specific sizes of tsunamis need to be envisaged in order to prepare intangible measures. Furthermore, it is sensible to envisage the frequency and size of a tsunami realistically by bearing in mind that concrete structures are useful for 50 years at most [1]. Accordingly, the following two sizes of tsunamis have been introduced [2, 3].

- Level-1 tsunamis: National and local governments ought to develop protective facilities in anticipation of the type of tsunami that occurs once every several decades or dozen decades

– Level-2 tsunamis: Municipalities ought to pursue disaster reduction to prepare for the type of massive tsunami that occurs once every several centuries

Of these two different tsunami sizes, it is obviously impossible to produce a clear definition for the probability of a massive Level-2 tsunami. However, even for the more frequently occurring Level-1 tsunamis, it is not necessarily possible to define their sizes through a probabilistic approach despite the fact that their cycles are known to be roughly several decades to dozens of decades. Nuclear facilities may well be prepared against Level-2 tsunamis, not to mention Level-1 tsunamis. This example only compares the height of an embankment with the expected degree of damage, but other measures could also reduce the level of expected damage.

II. Measures Taken for Key Facilities in Coastal Areas

A variety of key facilities can be found in coastal areas, including industrial, chemical, and power plants. These facilities are located in areas beyond those protected by embankments, so the following aspects of disaster management and reduction measures for these facilities should be considered by local communities and power utilities.

1. Devastation of Industry by a Tsunami and Its Recovery

Key facilities located outside of areas protected by embankments may even be affected by inundation caused by a Level-1 tsunami. Tsunami-related risks and their effects on key facilities need to be identified (clarification of weaknesses). In doing this, many scenarios should be envisaged by taking into account the various uncertainties associated with natural phenomena. The disaster triggered by the 2011 Tohoku earthquake affected many industries. Shibasaki [4)] estimates that an area submerged by about 2 m of water may take at least about 100 days to recover. However the amount of time required for an area to recover varies significantly depending on the type of industry, the surrounding environment, and the economic circumstances.

2. Measures Against Tsunamis to Ensure Business Continuity

Every effort must be made to simulate the resultant damage reliably based on the latest findings. Nonetheless, preparedness is necessary to facilitate the prompt assessment of damage caused by possible unanticipated events. Key facilities must build up an intelligence gathering capability that exceeds that of the public. They should also consider developing their own disaster management information systems since an amendment [5)] to the Meteorological Service Act now enables them to issue tsunami forecasts individually.

3. Impact on Surrounding Areas

If a structure must be built according to an appropriate business continuity plan, attention must be paid to its possible influence on tsunami heights in the surrounding area. To assess this possible influence, Arikawa et al. [6)] compared the tsunami height behind a new seawall with the tsunami heights in surrounding areas. As shown in **Figure 2**, this comparison

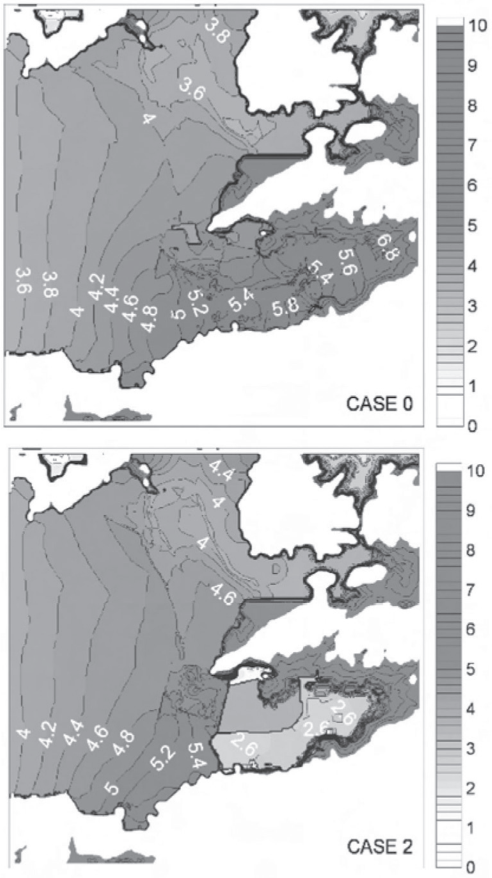

Figure 2 Comparison of tsunami heights before (top) and after (bottom) the construction of a seawall [6)]

demonstrates that the seawall reduced the tsunami height behind it by more than half. Notably, however, the tsunami height increased by roughly 60 cm in the area located to the north of the seawall after its construction. This increase was caused by a phase misalignment with the diffracted waves produced when energy is reflected back offshore after a landward intrusion. Given this, no sweeping judgements can be made about whether the construction of a seawall is a good or bad idea. In fact, an opposite phase can even reduce the tsunami height. For this reason, it is desirable for the impact of constructing a seawall to be closely examined through numerical simulations and necessary measures to be implemented, while engaging in consultations with local residents. The disaster caused by the 2011 Tohoku earthquake caused many types of unanticipated damage. To reflect on this lesson, it is crucial for community members, companies, and local governments to jointly identify the risks faced by society and continuously discuss and implement measures aimed at enhancing the local disaster management capacity.

III. Promoting Partnerships for Nuclear Disaster Management

1. Preparedness Against Nuclear Disasters Involving Tsunamis

(1) Nuclear emergencies and the challenges encountered during the disaster triggered by the 2011 Tohoku earthquake

In response to the accident that occurred at the Fukushima Daiichi Nuclear Power Plant, residents within a range of 20 km were ordered to evacuate one day after the earthquake struck. To facilitate this, buses were requisitioned to provide transport from an off-site center in Okuma. However, not enough buses could be dispatched from the respective municipalities due to coordination difficulties. According to a report by the Government Investigation Committee on the Accident at the Fukushima Nuclear Power Plant of Tokyo Electric Power Company, the major reasons for this include the understaffing of the Nuclear Emergency Response Headquarters, damage to roads due to the earthquake, and congestion from vehicles carrying evacuees [7)]. The investigation committee also identified problems in the choice of appropriate evacuation routes due to a failure to apply the radioactivity dispersion simulation results from the System for Prediction of Environmental Emergency Dose Information (SPEEDI) effectively [7)].

The massive tsunami devastated coastal settlements on the Oshika Peninsula, where the Onagawa Nuclear Power Plant is located. Residents there lost their homes to the tsunami and had to evacuate to shelters. However, the eastern half of the peninsula became inaccessible since the roads had been damaged by the earthquake and tsunami. Affected residents from surrounding settlements sought shelter at the nuclear power plant because they could not access other nearby shelters. The plant sheltered them inside. This experience demonstrates that, provided its soundness is maintained, a nuclear power plant can serve as a robust emergency shelter in the host community. The other side of the coin is that the provision of necessary assistance to the plant on the peninsula was complicated when access from other areas was disrupted by the damaged roads. In this respect, the Oshika Peninsula faces additional challenges due to its isolation in the immediate aftermath of a tsunami.

2. Nuclear Disaster Preparedness in Outside Areas

People must be evacuated swiftly without any trouble as soon as an evacuation order is issued in response to an increased risk of a nuclear emergency. The following measures are deemed important to ensuring that the host communities of nuclear power plants are prepared against tsunamis.

a) Build up the resilience of physical access from outside areas: Aseismic performance of roads and slopes around the area

b) Build up the resilience of off-site centers (e.g., against nuclear disasters) for responding to nuclear emergencies

Measure a) is even effective for evacuations in the event of a tsunami affecting a coastal area, a volcano eruption, and other such disasters, except that nuclear disasters involve a much larger scale of evacuation. Roads should be developed in anticipation of any such disasters in each area. In addition, nuclear emergencies should be anticipated in the development of roads in areas around nuclear power plants. Measure b) is necessary to facilitate information sharing among the relevant agencies during a nuclear emergency and to enable these agencies to respond effectively to a nuclear emergency (collection of radiation measurement data, delivery of information, and coordination of evacuation). The spatial distribution of the radiation dose predicted by SPEEDI should also be shared by learning from the failure to do so after the accident at the Fukushima Daiichi Nuclear Power Plant. The specific requirements can be found in the materials [8] compiled by the Nuclear and Industrial Safety Agency (NISA). They can be summarized into the following three key points:

a) Ensure the continuity of necessary functions even during a nuclear emergency that is compounded by the occurrence of more than one natural disaster
b) Secure alternative facilities
c) Conduct effective education and training under usual conditions and ensure its continuity

IV. Promotion of Local Partnerships for Nuclear Disaster Management

1. Importance of Risk Communication with Local Residents

(1) Challenges related to sharing information with local residents regarding the 2011 Tohoku earthquake and tsunami and the risks posed by the nuclear accident as well as pursuing local partnerships

The 2011 Tohoku earthquake and tsunami prevented the off-site center from responding properly to the subsequent accident at the Fukushima Daiichi Nuclear Power Plant. In addition, local residents were confused due to disruptions to the infrastructure for collecting and communicating crucial information on the nuclear accident and evacuation. Such problems should be avoided by promoting interactive communication among stakeholders and making the most of the limited time to discuss risk causes, factors, necessary measures, and their effectiveness with the aim of enabling decisions to be made with due consideration given to a diverse range of needs. For this reason, it is vital for trust to be built up under ordinary circumstances through regular interactive risk communication.

Going forward, nuclear risk communication should shift away from the conventional practice of making public addresses in public relations toward public acceptance. In other words, instead of expecting the public to simply receive and accept information, the focus should be on promoting interactive dialogues to incorporate the opinions of stakeholders into risk management measures in order to reduce risks. To build confidence in nuclear energy through risk communication, the first step involves clarifying the risk governance framework and mechanism for spiraling up nuclear safety. In the next step, information and opinions should be exchanged with local residents, the media, municipalities, and other stakeholders to incorporate their outcomes and reduce specific risks through risk management. To this end, risk profiles should be clarified and the effectiveness of protective measures, as well as their technical limitations and threshold criteria, should be presented in a scientific and reasonable manner. Also, intra-organizational risk communication (e.g., among the public relations department, the risk management department, and the engineering department) plays a significant role in risk management.

(2) Examples of risk communication practiced in the host communities of nuclear power plants

Certain outcomes have been obtained and compiled in earlier studies on practical risk communication in the host communities of nuclear power plants [9-11]. These studies examined how interactive (risk) communication has been practiced between power utilities and local residents as well as how it should be continued.

2. Enabling Technologies for Local Partnerships to Deal with Compound Disasters Involving Nuclear Accidents and Earthquakes, Tsunamis, or Other External Events

Already seven years before the 2011 Tohoku earthquake took place, the Japan Nuclear Energy Safety Organization (JNES) had been conducting research and development aimed at enabling technologies for local partnerships to deal with compound disasters involving nuclear accidents and natural disasters. The Indian Ocean earthquake and tsunami and the damage suffered by nuclear power plants in December 2004 prompted the JNES and member countries of the IAEA alike to recognize the importance of tsunami disaster management at and around nuclear facilities. To help improve the evacuation of residents in the event of a compound disaster involving a nuclear emergency and an earthquake or tsunami, the JNES has developed TiPEEZ (Protection of Nuclear Power Plants against **T**sunam**i**s and **P**ost-**E**arthquake Considerations in the **E**xternal **Z**one), a disaster response information system [12].

TiPEEZ consists of sub-systems for functions such as the following: assessing tsunami risks; providing informational support to surrounding municipalities by estimating evacuation plans for local residents based on estimated or actual damage to areas around the nuclear facilities caused by earthquakes and tsunamis; and sharing information with local governments and relevant agencies. Each sub-system functions autonomously in a coordinated manner to estimate the effective evacuation of residents by collecting and evaluating time-varying local information during compound disasters (**Figure 3**). TiPEEZ was provided to India in April 2009, and subsequently customized at the model site with technical assistance provided by the JNES. In February 2010, a simulated emergency drill was conducted using TiPEEZ at the

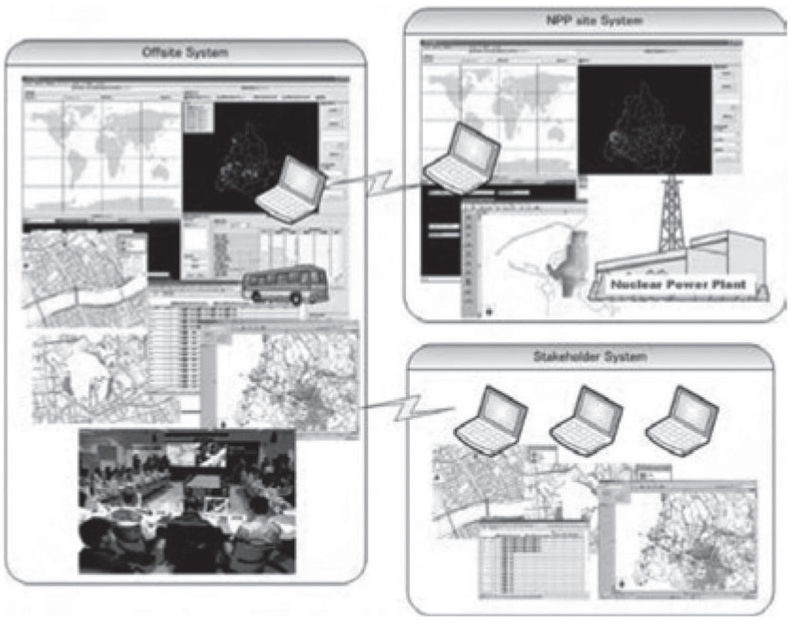

Figure 3 System configuration of TiPEEZ

headquarters of the Nuclear Power Corporation of India Limited (NPCIL) in Mumbai.

In Japan, following the disaster caused by the 2011 Tohoku earthquake, the local government of Kashiwazaki, a city where a nuclear power plant is located, requested technical assistance from the Niigata Institute of Technology, a local university, to plan some nuclear disaster response drills. In response to this, the university adopted TiPEEZ to perform the effective simulations needed to formulate nuclear disaster response drills involving earthquakes and tsunamis. This investigation on the applicability of TiPEEZ in the Kashiwazaki-Kariwa area was pursued through joint research conducted with the JNES [12]. In this investigation, the Niigata Institute of Technology, as a kernel institution, led some demonstrations aimed at local government personnel and local residents.

3. Promoting Partnerships Among Nuclear Facilities and Local Communities

Currently, the local governments of affected communities are required to take the lead in evacuating local residents pursuant to the Act on Special Measures Concerning Nuclear Emergency Preparedness and Nuclear Emergency Response Guidelines, as well as other relevant laws, regulations, and guidelines. Nuclear power utilities and the national government need a partnership framework for assisting these local governments. With respect to risk communication, the information obtained from risk assessments concerning natural external events around nuclear facilities contains important findings that may be useful for disaster management in surrounding areas. Seamless collaboration in dealing with nuclear emergencies, tsunamis, and other natural disasters can be expected if risk-related information is shared among the host communities of nuclear facilities and local residents. Going forward, a more specific framework should be developed to facilitate partnerships among nuclear power plants and host communities in addition to the necessary legal system. Furthermore, nuclear facilities are expected to collaborate with their host communities even beyond this legal framework.

V. Conclusions

As a land that is prone to tsunamis, Japan has sought to cope with tsunami hazards in a comprehensive manner through the adoption of tangible measures that involve the use of necessary structures in combination with intangible measures that mainly involve alerts and evacuation. The massive tsunami that was triggered by the 2011 Tohoku earthquake prompted the assignment of two levels to reflect tsunami sizes with the aim of developing tangible plans for disaster management and reduction. Measures for reducing damage to key facilities in coastal areas were also considered. In communities around nuclear facilities, preparedness is even more important in order to be able to cope with any facility-related accidents that may result from tsunamis.

Tsunami measures that form part of coastal conservation efforts are conducted jointly by prefectural governments and the national government pursuant to the Coast Act. Meanwhile, municipalities take the lead in planning local disaster reduction measures pursuant to the Basic Act on Disaster Management. Communities around nuclear facilities must additionally collaborate with private business operators to implement the comprehensive measures required under the Act on Special Measures Concerning Nuclear Emergency Preparedness. To better manage and mitigate tsunami disasters in areas around nuclear facilities, it is vital for power utilities as well as the national and local governments to fulfill their assigned roles in a coordinated manner and work together with municipalities and local residents.

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Preventing Recurrence of Severe Accidents at Nuclear Power Plants

−Think up Disaster Prevention along with Citizens for Nuclear Safety−

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Nuclear power generation carries with it inherent risks associated with radioactivity. The accident that occurred at the Fukushima Daiichi Nuclear Power Plant was the manifestation of such a risk. National and local governments, scientific communities, utility companies, manufacturers, and all other stakeholders were reminded of their responsibilities with respect to their roles involving nuclear power. The accident also served as a keen reminder of the importance for them to address the essence of nuclear safety. They need to ensure safety according to their roles in the design, operation, and disaster management of nuclear power plants. Risk assessments are vital as they allow stakeholders to provide substance to the necessary safety measures, divide the requisite roles amongst themselves, and verify their effectiveness in preventing abnormal events, mitigating their impact, and preventing and mitigating any damage from an accident involving the release of radioactive substances. More extensive risk assessments are recommended to cover hitherto neglected disaster management and cleanup measures in the aftermath of an accident. Doing so is expected to make power plants considerably more resilient to accidents and ensure nuclear safety.

KEYWORDS: Nuclear safety, scientific risk, social risk, risk assessment

I. Introduction

The magnitude 9 earthquake that struck the Tohoku region of Japan on March 11, 2011, was one of the strongest ever recorded in the country. The Fukushima Daiichi Nuclear Power Plant was also affected by the subsequent tsunami, and the resultant damage eventually led to a nuclear accident.

The direct cause of this accident was a failure to anticipate and adequately consider natural disasters. Important contributory factors later emerged through deeper analysis. For instance,

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earlier measures failed to address all of the possible types of natural disasters. Furthermore, accident management was insufficient in various respects, including an utter failure to respond to natural disasters and other external events beyond the design basis. No conceptual framework or system had been established to incorporate new scientific findings. The plant's emergency response was completely disabled by the lack of a systematic approach to the handling of the necessary equipment and the resultant failure of its vital safety functions when the supply of power as supporting components was lost. An effective emergency response could not be taken due to a failure to organize an appropriate command and decision-making system.

After the experience at the Fukushima Daiichi Nuclear Power Plant, an investigation commission was established to prevent the recurrence of severe accidents at nuclear power plants. Initially, in the fall of 2012, this commission was established following a proposal made by Hiroyuki Abe, the former president of Tohoku University. It started with his suggestion that "Every human-developed technology has been meaningfully developed. Efforts on how to use it as useful to humans are one of the important tasks of scientists and engineers." Nuclear power is no exception. Accordingly, the commission discussed the lessons that can be learned from the Fukushima Daiichi nuclear accident and the actions that need to be taken to put nuclear technologies to safe use. The conclusions of the commission were compiled into ten recommendations, which were then presented to the Nuclear Regulation Authority along with a report. These recommendations were also announced more widely to request their implementation by the relevant agencies. Most of them were put into practice after their incorporation into the new standards established by the Nuclear Regulation Authority. Unfortunately, efforts to make effective use of risk assessments remain inadequate despite this recommendation having the highest assigned priority. This is presumably due to a mixture of different reasons. One of the most important factors was probably the lack of social understanding. Hence, it was deemed necessary to explain the nature and benefits of risk assessments in order to gain the understanding of the public.

II. Recommendations and Measures for Preventing Severe Accidents

1. Purpose and Background

Anyone involved in nuclear energy must always remember the common sense belief held in other industries: there is no absolute safety. No matter how much you strive to ensure nuclear safety, the risk of an accident will always remain. Such risks must be discussed and addressed in tandem with wider society. In other words, a system must be established to promote comprehensive risk management and decision-making as a vital task that has been left to us in the wake of the Fukushima Daiichi nuclear accident. Some initiatives have already been undertaken toward this end.

In April 2013, the commission published a report on Phase I (with reference to a book published on January 20). In November 2013, the commission held a symposium aimed at enhancing nuclear power safety by adopting the risk concept, as social and scientific risks involved in nuclear. In April 2014, as a follow-up to the social and scientific risks involved in nuclear, an international symposium was held to discuss optimal countermeasures for earthquakes, tsunamis, and other natural hazards. At this symposium, a social dialogue was conducted in an attempt to determine how much understanding could be gained with respect to risk assessments for nuclear safety. Unfortunately, it proved quite difficult to gain an understanding of the risks and risk assessments.

In 2015, the commission sought to conduct participatory risk assessments by engaging the wider society, shifting away from the traditional approach of risk communication and efforts to seek an understanding of the risks involved. The commission began to exchange views with the municipal personnel responsible for nuclear disaster management. A workshop was also held in October to facilitate an exchange of views on risks and nuclear disaster management.

In this manner, after a process of trial and error, the commission finally began to put participatory risk management into practice.

2. Implementing Recommendations to Address Root Causes

The root causes of the Fukushima Daiichi nuclear accident can be categorized as follows: (1) inadequate anticipation of natural disasters; (2) insufficient accident management measures; (3) ineffective disaster management system; and (4) failure to learn lessons from international exchanges (particularly with respect to initiatives involving risk assessments). With these causes in mind, the commission concluded that they needed to re-examine whether it was appropriate to have allowed utility companies operating nuclear power plants to be responsible for ensuring safety themselves and what the national government and regulatory authorities should have done. The results were compiled into ten recommendations, which were also shared with the public. The key recommendations were as follows: ensure adequate responses to unanticipated events (Recommendation 1); implement highly evaluated world-class measures (Recommendation 2); implement concrete measures for preventing and mitigating accidents with proper recognition given to the assigned responsibilities (Recommendation 3); and engage all parties in discussions of the risks involved and the necessary countermeasures (Recommendation 4). Some of these recommendations have already been incorporated into the new regulatory standards. Many of them have been implemented with adequate equipment having been put in place.

3. Remaining Challenges: Role of Risk Assessments

The accidents that preceded the Fukushima Daiichi nuclear accident have inevitably involved design-related issues. Hence, the designs of nuclear power plants should be constantly revised. Many past incidents have also involved human error, other human factors, and malfunctions. Western countries were already conducting risk assessments in order to ensure safety even during unanticipated events. The Fukushima Daiichi nuclear accident revealed that Japan was lagging behind its counterparts in this respect. The new regulatory standards are mostly focused on factors involving designs, while accident management and other measures address problems associated with equipment. Other intangible soft measures remain inadequate. In contrast, Western countries have long been conducting these risk assessments in earnest to improve their measures, particularly since the Three Mile Island accident.

To comply with defence in depth, safety is pursued by implementing measures independently of the design, operation, and disaster management of nuclear power plants. The roles that these measures play are respectively assigned according to the results of risk assessments to reduce risks effectively.

The term “risk” can be expressed as the product of the probability of an event and the magnitude of the consequences. The same yardstick for consequences must be employed to evaluate a variety of different types of risks on an equal basis. Until now, the magnitude of consequences has been expressed as the mortality. One disadvantage of this yardstick is that it cannot adequately express smaller risks. As a possible alternative, the amount of released radioactivity can be considered as a rough indicator of environmental pollution. In Fukushima, the measures that were taken with respect to the design were insufficient, and any measures taken with respect to operations and disaster management were inadequate. As a result, almost 10 PBq of radioactive substances ended up being released. This radioactivity did not harm people directly, but the poorly coordinated evacuation resulted in roughly 200 casualties among the sick and elderly. Appropriate preventive and mitigation measures in relation to the plant operations would have resulted in a much lower release of radioactive substances. Similarly, better preparedness in terms of disaster response would have helped to avoid the casualties caused by the poorly coordinated evacuation. A new risk target of 100 TBq, for instance, is feasible as long as appropriate measures are adopted in the relevant areas as well as with respect to the design and operations. In other words, ensuring low risk in individual areas can ensure safety and, of course, lead to an overall risk reduction and safety.

Recommendations 3 and 4 imply that risks cannot be addressed simply by adopting hardware measures to prevent accidents involving equipment. These recommendations serve as reminders that nuclear safety must also be ensured by addressing risks associated with the design, operation, and disaster management of nuclear power plants to reduce the impact that radioactive substances have in the respective areas. Rather than pursuing absolute safety through hardware measures alone, appropriate safety measures ranging from operational management to disaster management must be considered and chosen to reduce risks while engaging the wider society in the process. A consensus-driven system must be established to steer this approach in a direction that gains support and understanding. Risk assessments are the bedrock of such a system.

III. Risk Analysis and Assessments for Disaster Management

1. Application of Risk Assessments for Disaster Management in General

Society faces a variety of threats and hazards, such as earthquakes, tsunamis and volcanic eruptions as well as the heavy rains caused by typhoons. An example is presented to explain a suitable evacuation plan for addressing threats and hazards, carrying out an evacuation in response to an escalating event, and implementing any other measures for disaster management.

In the management of disasters in general, risk assessments are conducted with the aim of minimizing the total number of human casualties among residents as a risk. **Figure 1** shows some examples of hazard factors, which are threats to society that can cause a disaster. In this context, starting from the occurrence of a disaster from these hazard factors, a risk is considered a combination of the likelihood of a hazard event as a disaster (a hazard map is usually produced)—and the anticipated extent of damage to residents. A disaster management plan should be developed by accurately evaluating what types of measures can change the risks levels and to what extent.

2. General Disasters and Risk Assessments

Choosing the right indicator to monitor the threats posed by hazards is challenging. The indicator must vary with time and facilitate decision-making related to the preparation and initiation of an evacuation. Decisions concerning the issuing of evacuation orders and the like must be made early enough to ensure proper sheltering and evacuation.

Once a decision has been made to initiate an evacuation, the hazards and threats involved in the evacuation process must be considered along with their likelihood and feasibility. Any disaster management planning that is conducted in advance of an evacuation decision should bear in mind that the ultimate risk levels depend on which of the given options is chosen. Obviously, disaster management does not end with the evacuation. Risk assessments may be applicable and useful in deciding how the reconstruction and the restoration of normalcy should be pursued after the evacuation.

In the event of a river flooding due to a typhoon, for example, the extent of damage will vary depending on which of the following choices is taken: wait at home, evacuate during the flooding, or request a rescue.

As shown in **Figure 2**, a hazard must be quantified for a suitable response to be taken. A hazard is quantified along the vertical axis, which changes over time. A decision on the waiting at home or initiation of an evacuation is made while taking into account the necessary amount of time and the threshold level of the hazard. A decision is not made according to a blanket procedure. It depends on the intended targets, their respective environments, and

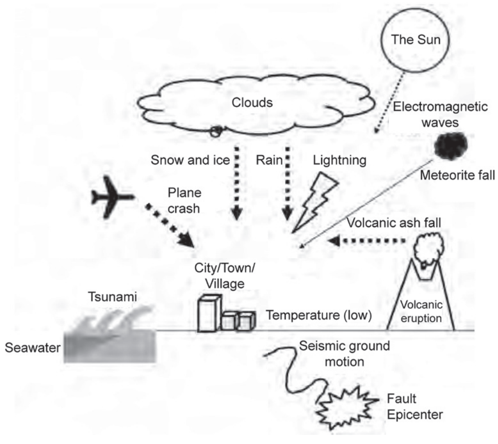

Figure 1 Examples of threats to society

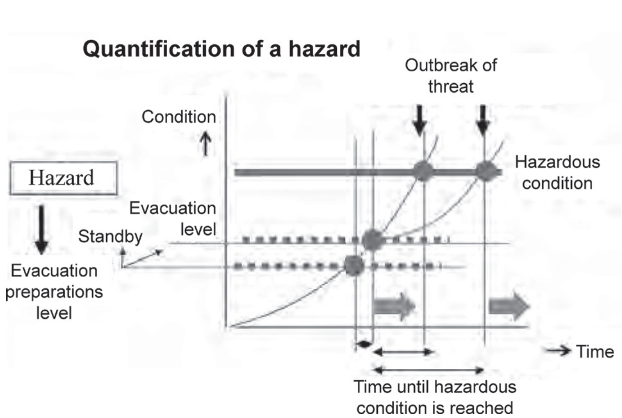

Figure 2 Decision-making related to an evacuation based on a quantified hazard

other conditions. An evacuation may even begin during the standby phase. The analysis of hazards should also be part of risk analysis.

3. Application of Risk Assessments for Nuclear Disaster Management

This section describes how risk assessments are employed for nuclear disaster management in a way that is analogous with their application in the management of disasters in general. Hazards involving nuclear disaster management pose a threat to residents just like earthquakes, tsunamis, typhoons, and the like in the context of the management of disasters in general. A threat to residents involved in nuclear disaster prevention is the release of radioactive substances from nuclear power plants. Theoretically, an evacuation can be decided based on an appropriately defined indicator. In current practice, however, the evacuation of residents from a particular area is initiated as soon as radioactive substances are released from a power plant or the national government orders it. The same evaluation method is employed despite the fact that the risks involved in evacuations from different starting points vary according to the evacuation routes and conditions. In a risk assessment, appropriate risk reduction measures can be obtained by considering what is defined as a risk, what constitutes an acceptable risk, and how a risk can be reduced.

Nuclear disaster management must take into consideration the risks borne by residents from an extended area. How such risks should be aggregated as a social risk is something that will need to be considered in the future along with an effective means of applying risk values.

4. Relationship Between the Management of Nuclear Disasters and That of Disasters in General

The management of nuclear disasters seems no different from that of disasters in general with respect to the ways in which events escalate and how risks are assessed. **Figure 3** provides an overview of risk analysis and assessments. Instead of winds, flooding, and the other hazards posed by general disasters, nuclear disaster management deals with the diffusion and fallout of radioactive substances. In sharp contrast to the visible hazards associated with general disasters, nuclear accidents require measures for dealing with the invisible hazards posed by radioactive substances. The important challenge is how such differences should be factored

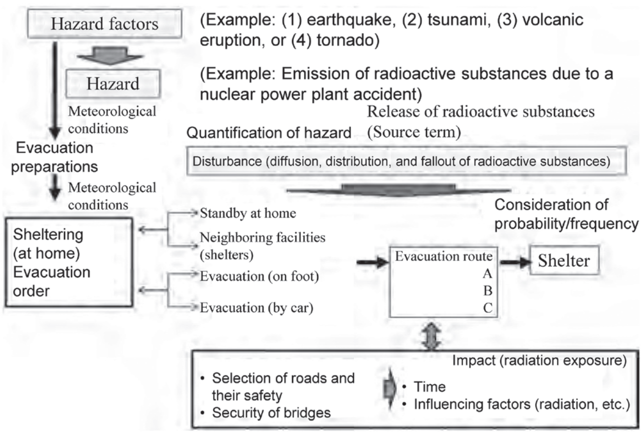

Figure 3 Hazards and risk assessments in nuclear disaster management

into risk analysis and assessments.

The same assessment approach is taken with respect to the risks involved in the escalation of nuclear accidents inside power plants and the measures taken outside. The key here is the method by which escalating events are identified in the example shown in Figure 2. In other words, without the quantification of a hazard to identify an escalating event, a suitable response cannot be taken. At the same time, when an accident at a power plant progresses and radioactive substances are released from the power plant, if the extent of this release cannot be ascertained, the residents are considered to be in an emergency. However, it is not just difficult to understand the situation and difficult to take disaster prevention measures after an accident occurs, it is extremely difficult.

Risk assessments, therefore, must be performed while bearing in mind that the target events are invisible.

5. Engaging the Wider Society in Risk Assessments

Communities and nuclear power plants alike suffer in the event of a natural disaster. Such events may lead to complex nuclear emergencies, and the community must consider how to deal with compound events. Until now, the risk assessments performed at nuclear power plants have been focused on damage to the equipment, reactor cores, and primary containment vessels. Level 3 probabilistic risk assessments used to be conducted using a simple model to assess the risks to the public, and they supposedly ensured a high level of safety. Nonetheless, the risks posed by nuclear accidents must ultimately be carried by the local communities and society as a whole. Given this, simply assessing the risks associated with an escalating event from the perspective of nuclear power plants is not enough. Risk assessments must be conducted from the perspective of local residents by considering which risks should be borne, to what extent they should be borne, and how a disaster should be managed. These approaches must be combined in the pursuit of nuclear safety.

IV. Nuclear Safety with Participatory Disaster Management

1. Application of Risk Assessments for Disaster Management

The resultant consequences and probability of disasters can be reduced through the appropriate design, operation, and disaster management of nuclear power plants.

Given the increasingly complex nature of the hazard factors, the authors believe that nuclear safety can be ensured by considering and addressing all of the various types of risks involved in both natural and human-induced events in a comprehensive manner. Until now, the risk assessments conducted by the nuclear sector have been focused on the safety of equipment at nuclear power plants. In terms of disaster management, though, they simply suggested the performance of basic additional assessments because they believed that requiring an evacuation would be sufficient in the event of a highly unlikely accident. However, such risk assessments were seldom conducted. Nuclear safety and disaster management should be pursued from the perspective of local residents. Risks should be defined by involving the public in the thinking process. The key task going forward is to determine how this process should be managed and who should assume responsibility for it.

Risk assessments for the use of nuclear power require definitions of the risks involved as well as clarification of how scenarios should be considered and how the assessment results

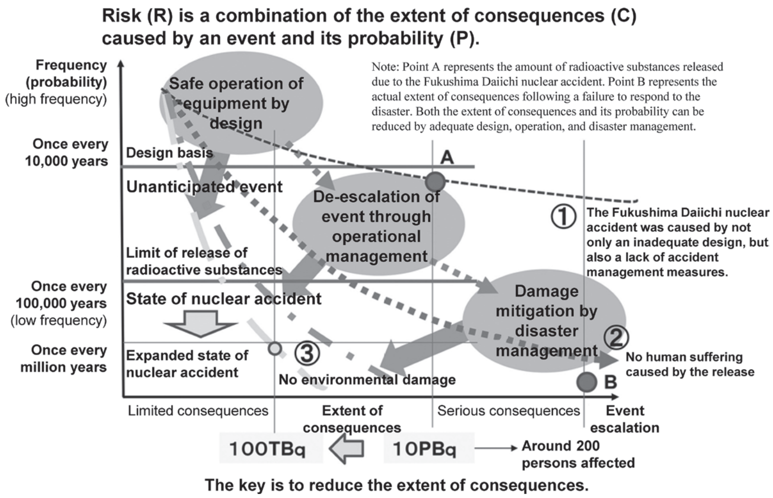

Figure 4 Total risk assessment to ensure safety

should be applied. As shown by the schematic illustration in **Figure 4**, such assessments are intended to reduce both the degree of consequences along the horizontal axis and the probability or likelihood along the vertical axis. Risk reduction during the design phase is pursued to ensure the safe operation of equipment by adopting a robust design, while risk reduction during the operational phase is intended to deescalate events through appropriate management and respond to events that may lead to an accident beyond the design basis. Combined with these efforts, the performance of disaster management to mitigate damage in accordance with the figure can maximize nuclear safety and minimize the risks involved in a nuclear accident. Going forward, risk management should engage all stakeholders as a whole society; in other words, local community members, the public, nuclear experts and risk experts, manufacturers, municipalities, and regulatory. The application of risk assessments in disaster management serves as an important interface toward achieving this goal. Such a practice is expected to ensure nuclear safety and reduce risks more effectively.

2. Engaging the Wider Society in the Pursuit of Nuclear Safety

The discussion so far has covered risk perceptions in society and risk communication as a means of dialogue. Nuclear safety must be pursued in every phase—from the design of a nuclear power plant through its siting, construction, and operation to disaster management—by implementing risk mitigation measures to prevent the potential risks of the radioactive substance release from becoming imminent threats. Otherwise, well-balanced and effective measures must be implemented to reduce the overall risks. This comprehensive approach to risk mitigation and risk assessments is unprecedented. In the past, concerns were focused on the balance between the risk assessments and risk reduction measures devised by experts on behalf of the nuclear sector. Going forward, participatory risk management must be pursued by engaging the public. Similarly, measures adopted in disaster management to mitigate risks ought to be considered by adopting the concept of risks. Measures aimed at ensuring nuclear safety will hopefully be established by the wider society in a more transparent manner so that the public can keep track of them.

V. Conclusions: Why Are Risk Assessments Important?

This commentary has discussed how social acceptance of risk assessments can be gained by promoting a deeper understanding of their importance. In fact, even in the nuclear sector, many people and groups still do not understand the importance of risk assessments.

Why are risk assessments important?

One possible reason for their importance is the need to minimize phenomena that cannot be anticipated. Many scenarios can be adopted to reduce unknown factors and minimize phenomena that cannot be anticipated. Important decisions can be made objectively by adopting common judgement criteria and quantified risk values in risk assessments of matters ranging from the design and operation of nuclear power plants to disaster management. Doing this enables suitable safety measures to be devised. Disaster management combined with the concept of risks can help engage the wider society in the consideration of matters such as the risk assessment results, the safety goals to be assigned, associated uncertainty, and unknown factors. Nuclear Scientists, engineers, and the public can share the same perspective on the decisions that are made. It would be beneficial to engage the wider society in discussions of what the risks are and how they can be mitigated through joint action.

Risk assessments have already been conducted with respect to the risk factors associated with nuclear power plants. Initiatives aimed at applying risk assessments to disaster management as explained in this commentary will help to formulate a consistent practice of conducting risk assessments in every phase, from manufacturing and operations all the way through to disaster management, and thereby stimulate cross-sectional discussions and partnerships. To this end, it would be necessary to develop human resources in the conducting of risk assessments and promote risk literacy among people. (February 26, 2016)

Acknowledgments

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Survey of Public Opinions in Areas Close to Hamaoka Power Station in Shizuoka

−Generational Differences in the Levels of Acceptance of Nuclear Power−

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A questionnaire survey was conducted to address various matters involving the use of nuclear power in four communities near the Hamaoka Nuclear Power Plant, which is located in Shizuoka Prefecture and operated by the Chubu Electric Power Company. Analysis of the nearly 7,600 responses has revealed generational differences in the levels of acceptance of nuclear power. The younger generations proved to be more pro-nuclear. Moreover, a higher share of respondents among the elderly was found to result in age bias. In fact, voices in favor of resuming the use of a nuclear power plant after completion of the due safety review outnumbered those against it when responses were weighted according to the actual age composition in Japan. This survey has also demonstrated what needs to be done to deepen our understanding of nuclear power. This first commentary reports the survey findings.

KEYWORDS: Hamaoka nuclear power plant, public acceptance of nuclear power, survey of public opinions, energy mix, climate change

I. Introduction

This questionnaire survey was inspired by papers that analyze responses to public opinion surveys on nuclear power in the United Kingdom and the United States. The Japanese media and municipalities tend to conduct questionnaire surveys on nuclear power mostly using simple yes-no questions, such as whether the respondents are in favor or against the resumption of nuclear power generation.

In the West, questionnaire surveys tend to consist of detailed questions aimed at, among other things, gauging the level of interest in environmental issues and energy security among the respondents. The author decided to conduct a survey in this manner rather than asking simple yes-no questions in order to weigh the responses based on the level of interest in energy security and global warming. The findings from this survey were expected to serve as a reference for the formulation of nuclear and energy policies.

The survey targeted communities in the city of Omaezaki, which hosts the Hamaoka Nuclear Power Plant operated by the Chubu Electric Power Company, as well as the three

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neighboring cities of Kakegawa, Kikugawa, and Makinohara. Questionnaire surveys in the United States and the United Kingdom indicate a high degree of acceptance of nuclear power among the host communities, but this acceptance is not necessarily shared among neighboring communities. The survey was conducted to confirm whether, as expected, the same tendency could be observed in Japan.

Just under 40,000 questionnaires were distributed in the four target cities from mid to late November 2015. Approximately 7,600 responses had been collected by mid-December. The results from an analysis of these responses are reported in two commentaries. This commentary analyzes the implications of these responses and, based on the findings, the next commentary will identify issues that need to be considered while formulating policies on nuclear and other energy sources.

II. Questionnaire Survey and Opponents of Nuclear Power

A few days after the questionnaires were mailed out, a journalist from a newspaper publishing company known for its anti-nuclear stance phoned us to ask whether some of the questions were posed in an attempt to lead the respondents into supporting nuclear power. The topics addressed in the questions that the journalist mentioned are listed in **Table 1**. The questionnaires stated facts about Japan's energy self-sufficiency rate, the country's degree of dependence on oil and gas imports from Middle East, and the state of global warming as well as the increased purchasing of fuel and rising electricity prices since the shutdown of nuclear power plants. These factual explanations are intended to analyze differences in responses based on the level of interest in energy and environmental issues. If questions such as these could be considered as leading, it would be impossible to conduct surveys that include factual explanations.

After listening to our explanation, the journalist followed up by asking why anti-nuclear views are not included in the questionnaire. Obviously, neither anti-nuclear views nor pro-nuclear views are presented in this questionnaire since it is intended to find out the views of the respondents based on facts. Given this, we explained that pro-nuclear views are not presented either. On the contrary, only objective facts are stated in adherence with the spirit of the questionnaire survey. A few days later, opponents to nuclear power organized a press conference to protest against our allegedly leading survey. Rising electricity prices seem to be an inconvenient truth for some people who oppose nuclear energy.

Our laboratory received dozens of phone calls because we included the phone number so that respondents could contact us if they had any inquiries about the questionnaire. The inquiries were almost equally divided into questions related to the content of the questionnaire and opinions in favor or against nuclear power. Those who favored nuclear energy mostly appreciated that the questions were intended to capture views that are hard to classify with yes-no

Table 1 Survey topics related to energy and environmental issues

- Imports of fossil fuels
- Risks posed by the Strait of Hormuz
- Impact of global warming
- Discussions at the COP 21 climate talks
- Japan's greenhouse-gas emissions targets
- Additional fuel costs
- Rising electricity prices for households
- Rising electricity prices for industry

questions. They encouraged us to conduct more extensive surveys in this manner.

Nuclear skeptics were divided into two groups. Some hung up after unilaterally accusing us of leading respondents to answer in favor of nuclear energy. Other self-declared opponents identified matters that were unclear in an honest effort to find out more about nuclear power. Their questions often stemmed from misunderstandings. Due consideration must be given to encouraging these people to acquire correct information and gain a deeper understanding of nuclear power.

III. Perils of Public Opinion Surveys Conducted by the Media

Most questionnaire surveys conducted by the media ask respondents if they are in favor or against the resumption of nuclear power generation. For instance, an article dated February 16, 2016 that appeared in the *Asahi Shimbun, a nationwide major news paper,* features a survey conducted from January 16 to 17. Asked if the suspended operation of nuclear power plants should be resumed, 31% of respondents were in favor and 54% were opposed.

Our questionnaire included the same question. As the age composition of the survey respondents in **Table 2** shows, the respondents were unevenly distributed among different age groups. In Japan, people aged 60 and above account for 32.6% of the population. More than half—or 53.1%—of the respondents belonged to this age category. **Figure 1** shows the overall share of each view after the responses have been adjusted in line with the latest population composition of Japan. Broken down by age group, the responses demonstrate that, with age, people develop a more negative attitude toward the resumption of nuclear power generation, even after the completion of a due safety review. Opposition is strongest among people in their 60s.

Making this adjustment based on Japan's population composition results in over 50% of respondents being in favor of the resumption, a fact that demonstrates the perils of simply tallying the responses. The same problem may be affecting other questionnaire surveys conducted by the media(*). The aforementioned survey by the *Asahi Shimbun* sought responses by calling randomly sampled phone numbers, but it is important to note that few young people have landline phones in their homes nowadays. Moreover, only 1,943 persons (about 50%) of the owners of the 3,909 sampled household phone numbers responded to the survey. As you

Table 2 Response rate and Japan's population composition broken down by age group

Age group	Percentage of total responses [%]	Percentage of total population [%]
Teens	0.5	9.3
20s	1.8	10.3
30s	4.5	13.1
40s	10.2	14.2
50s	19.9	12.1
60s	36.5	14.4
70s and older	26.6	18.2
Total	100.0	91.6

Note: The population composition is based on materials obtained from the Ministry of Internal Affairs and Communication (2013)

* As we later discovered, the results from surveys conducted by the media were also adjusted according to the population composition. Consequently, the relevant discussion is to be removed.

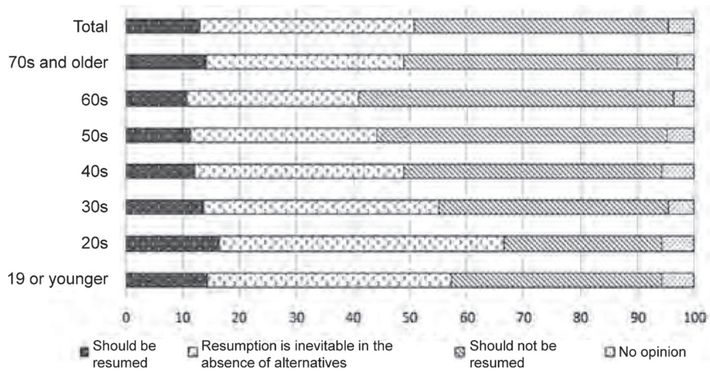

Figure 1 Stance on resumption broken down by age group
Note: The overall proportion was adjusted based on the population composition according to the Ministry of Internal Affairs and Communication.

Table 3 Opinions on possible resumption broken down by gender

	Total	Male	Female
Responses	7513	4970	2461
Should be resumed	12.2	15.5	5.4
Resumption is inevitable in the absence of alternatives	33.5	33.6	33.2
Should not be resumed	50.3	48.0	54.9
No opinion	4.0	2.9	6.5

Note: Raw data without adjustment by age group. The total figure includes 83 respondents who declined to specify their gender.

might imagine, the majority of the respondents represented senior age groups.

In conducting their opinion surveys, the media must keep up with the times and advances in information technologies. Simply tallying the responses obtained via outdated landline phones will almost certainly cause the results to be heavily biased by the views of the elderly. It is more prudent to suspect the presence of age bias in a public opinion survey if a breakdown of the respondents by age group is not presented.

Admittedly, fewer women responded to our survey, with a ratio of roughly two males to one female. Furthermore, women tend to be relatively more opposed to the resumption of nuclear power generation, as shown in **Table 3**. Adjusting the results for age and gender will probably result in a slightly lower share of respondents being in favor of the resumption. In addition, the responses vary depending on the respondents' places of residence and occupations.

IV. How Places of Residence and Occupations Influence the Level of Acceptance for the Resumption of Nuclear Power Generation

The locations of the four target cities are presented in **Figure 2** along with the preliminary population counts from the census conducted on October 1, 2015. The response rates in the local populations were 3.7% in Kakegawa, 3.1% in Omaezaki, 3.3% in Kikugawa, and 3.5% in Makinohara. As a host municipality, Omaezaki had a slightly lower response rate but it was still much the same as that of the neighboring cities.

Opinions diverged between Omaezaki and the three neighboring cities regarding the possible resumption of nuclear power generation, as expected based on earlier studies conducted in other countries that pointed to greater support for nuclear power in host communities. As the responses broken down by city in **Figure 3** show, negative views have a relatively higher share without adjustment by age group.

The survey also gauged the level of interest in energy and environmental issues. In response to a question asking if they realized that the shutdown of nuclear power plants had led to a rise in fuel costs, a higher share of respondents from Omaezaki responded that they were aware of this compared to their counterparts in the three other cities. This fact suggests that host communities tend to be more interested in rises in fuel costs caused by the shutdown of a nuclear power plant.

At times, newspersons have told us that they agonize over how much they can touch on the issue of the possible resumption of nuclear power generation given that most of their viewers are homemakers opposed to nuclear energy. As mentioned earlier, our survey also confirmed

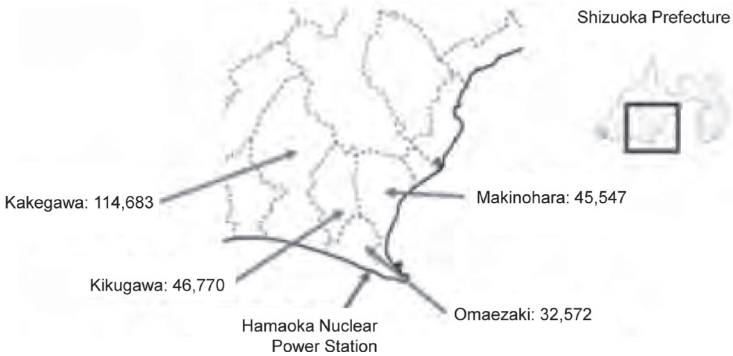

Figure 2 Map of area around the Hamaoka Nuclear Power Plant
Note: The local population is indicated after each city name.

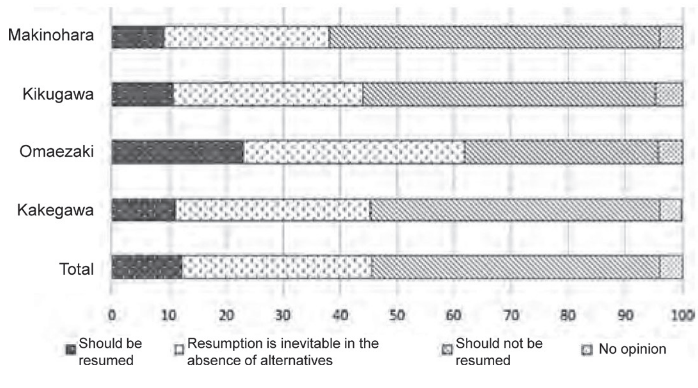

Figure 3 Opinions on possible resumption in each city
Note: Raw data without adjustment by age group. The total figure includes 83 respondents who declined to specify their gender.

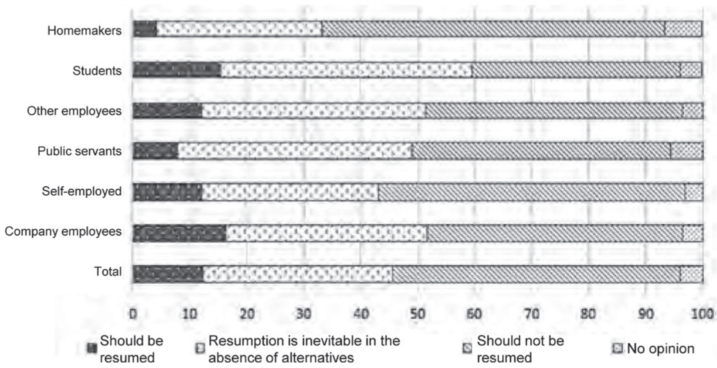

Figure 4 Opinions on possible resumption broken down by occupation
Note: Raw data without adjustment broken down by age group.

that women tend to be more opposed to the resumption.

The greatest share of respondents to this survey had no occupation, most probably due to their ages. This share of roughly 29% was followed by the following: company employees (24%), self-employed (16%), homemakers (14%), and public servants (4%). The combination of responses indicating that nuclear power plants should be resumed or that resumption is inevitable in the absence of alternatives outnumbered those expressing opposition to resumption among company employees, public servants, other employees such as group staff, and students. Homemakers were the most opposed to the resumption, as shown in **Figure 4**.

Respondents who are more interested in energy or environmental issues tend to be relatively more in favor of the resumption of nuclear power generation than those who are less interested in such issues. This analysis will be discussed further in the next commentary.

V. Opinions on the Additional Construction of Nuclear Power Plants

The government of Japan has announced a goal of supplying between 20 and 22% of its electricity from nuclear energy by 2030, along with 22 to 24% from renewable energy, 3% from oil-fired thermal power, 26% from coal-fired thermal power, and 27% from LNG. This target for the energy mix of power sources is combined with a goal for 2030 of enhancing the country's energy efficiency by 35%.

These goals embody the national government's commitment to reducing greenhouse gas emissions by 26% by 2030 from the 2013 level under the Framework Convention on Climate Change. A total target share of 44% was presumably assigned to nuclear and renewable energy as low-carbon sources of power, which still required energy savings of 35% to fulfill the Japanese commitment. It is safe to say that these goals were calculated backwards from the commitment to reduce greenhouse gas emissions.

The proportion between the two low-carbon sources of power seems to have been decided based on estimates of electricity prices. An increase in the share of renewable energy encouraged by a feed-in tariff would inevitably push up electricity prices. Most probably, the proportion of nuclear and renewable energy was decided based on the estimated share of renewables that would still not push up electricity prices.

An increase in the share of nuclear energy from the current level to between 20 to 22% would require the operation of some nuclear power plants to be extended from 40 to 60 years and some existing plants to be replaced with new plants. Otherwise, some new plants may need to be additionally constructed. Responses to questions on the additional construction and replacement of nuclear power plants are shown in **Figure 5**. An almost similar trend as that associated with age groups can be observed with respect to stances on the possible resumption of nuclear power generation after safety reviews. Nonetheless, fewer respondents support the additional construction or replacement of plants as compared to their resumption.

Similarly, relative to the level of support for the resumption of nuclear power generation, fewer respondents favored the government policy of setting a target share of 20% for nuclear power. The latter share was similar to the shares observed for favorable stances toward the additional construction or replacement of nuclear power plants. It will be difficult to achieve the goal of reducing greenhouse gas emissions without public support for the government policy of increasing the share of nuclear power to 20%. This weak level of support stems from low trust in the national government.

Figure 6 presents the level of trust in the national government among respondents from the four target cities. The number of respondents in Omaezaki who expressed the view that the

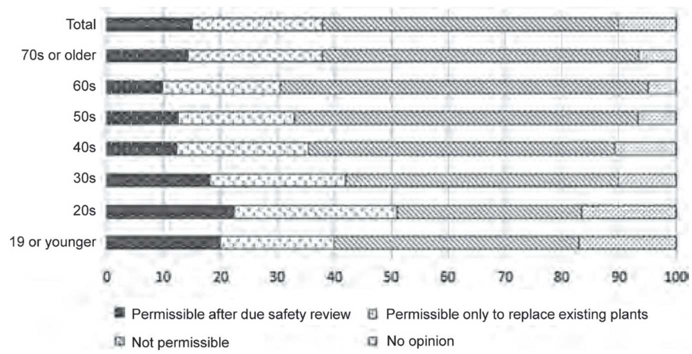

Figure 5 Stances on additional construction broken down by age group
Note: The overall proportion was adjusted based on the age composition according to the Ministry of Internal Affairs and Communication.

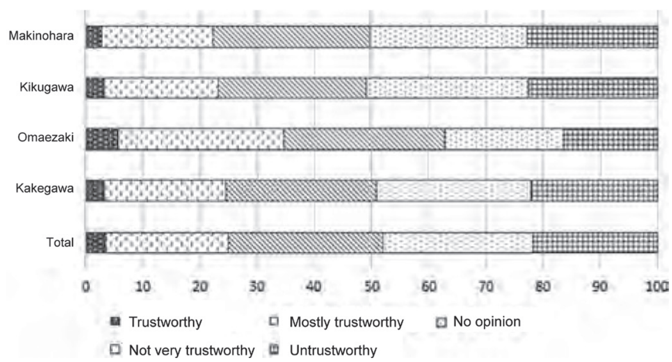

Figure 6 Level of trust in the national government

national government is trustworthy or mostly trustworthy exceeded that of respondents in the other three cities. Nonetheless, the number of these respondents was lower than the number of those who expressed the view that the government is not very trustworthy or untrustworthy.

VI. Trust in the Government Must be Enhanced

The government has announced an energy mix target for power sources in 2030. Nonetheless, steps to increase the share of nuclear power from the current level to from 20 to 22% have not been clarified. It takes more than 10 years to construct an additional plant or replace an existing plant. Consequently, as soon as the necessary power output from nuclear power plants for 2030 is specified, the government must immediately clarify how the target can be achieved. Otherwise, it will be difficult to achieve the targets for greenhouse gas emissions and the energy mix of power sources. Unless this process is clarified, trust in the government will remain low.

Respondents from the four cities indicated a relatively higher level of trust toward the Chubu Electric Power Company compared to their level of trust toward the national government and its nuclear policy. In particular, the power utility company was considered trustworthy or mostly trustworthy among 47.2% of respondents from Omaezaki. This share far exceeds the 29.3% of respondents who regarded the utility company as not very trustworthy or untrustworthy.

The relatively higher level of trust toward the utility company compared to the government could conceivably result from familiarity with company employees in the local communities who have personalities that inspire confidence. The utility company can also offer more in-depth explanations to local residents.

Therefore, face-to-face explanations seem to be the key to gaining trust toward nuclear power. What types of explanations should be provided? The next commentary will discuss the relevant findings from our questionnaire survey.

Looking Back Five Years of Fukushima
–Progress of Environment Decontamination and Radiation Risk Communication–

High Energy Accelerator Research Organization (KEK), **Masayoshi Kawai**

Five years have passed since the Great East Japan Earthquake of 2011. This commentary on decontamination work and radiation risk communication reflects on the activities that the author has actively engaged in during these years and identifies some of the challenges ahead. In particular, this work has been a battle against the mistaken belief that comes from an impatient demand to reach the long-term decontamination target of 1 mSv/y. The achievements secured through the more rational approach adopted by the city of Date suggest that the target should have been set at 5 mSv/y. This commentary further considers how to enable evacuees to return to their homes and dispel the lingering and harmful rumors.

KEYWORDS: Fukushima, decontamination, radiation risk communication, radiation exposure, spatial dose rate, 1 mSv/y, natural radiation

I. Introduction

Five years have passed since the Great East Japan Earthquake. This is the final year of the decontamination work being conducted in Fukushima Prefecture. Immediately after the nuclear plant accident, Fukushima-shi and another centrally located major city, Koriyama, recorded a dose rate of over 10 μSv/h due to radiation from iodine-131 (I-131), which has a half-life of 8.0252 days. The long-term target of reducing the annual additional exposure dose in living environments to 1 mSv/y has been achieved in these cities and other areas, with the exception of restricted residence zones and difficult-to-return zones. Personal dosimeters registered a substantive annual cumulative dose of less than 1 mSv even in the highly contaminated parts of Tamura, Kawauchi, and Naraha, where evacuation orders have been lifted. Decontamination work in the remaining areas will be completed so that evacuation orders can be lifted.

Nevertheless, there are still roughly 100,000 evacuees from Fukushima Prefecture (55,000 living inside the prefecture and 43,000 living outside the prefecture) [1]. Responses from evacuees to a questionnaire on their intention to return home suggest that it is hard for evacuees from communities where evacuation orders have been lifted to return home. What

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should be done now and what measures will it be possible to take if a similar emergency happens again in the future? To answer these questions, the author mainly discusses decontamination work and radiation risk communication by reflecting on activities carried out in the past five years.

In the immediate aftermath of the disaster, the author participated in volunteer decontamination work in Date and Minamisouma in fiscal 2011, where he gained some of the hands-on skills involved in the performance of decontamination work. He specializes in radiation technologies (particularly neutron-related ones) and learned radiation risk communication by himself. In fiscal 2012 and 2013, he was in charge of public relations at the Fukushima Office for Environmental Restoration, which was established by the Ministry of the Environment. He engaged in public relations activities related to decontamination projects, supervised the operation of the Decontamination Information Plaza, and was involved in radiation risk communication. He sometimes participated in discussions and site visits with experts from the International Commission on Radiological Protection (ICRP) and the International Atomic Energy Agency (IAEA). He has also attended dialogue forums, etc., with local residents on behalf of the office.

The author's summary of a Community Dialog Forum for Residents of Fukushima Prefecture with International Experts that was held in Fukushima in November 2012 has been published in this journal [2)]. At this forum, which was moderated by ICRP experts, residents of Fukushima Prefecture shared their experiences of being forced to evacuate without any knowledge of radiation or any adequate information. They also talked about the issues that they faced later. The Fukushima Office for Environmental Restoration provided explanations of the decontamination projects, while ICRP experts provided advice on how to deal with radiation. They explained that radiation doses in Fukushima should not be considered problematic because the doses in Fukushima are comparable to those caused by natural radiation in other countries. They stressed the importance of radiation risk communication to ease concerns over radiation and dispel harmful rumors about food products from Fukushima Prefecture. Full-scale decontamination work began that year (2012), and many rounds of briefing sessions were held to acquire consent from local residents for the decontamination work and the construction of temporary storage yards for the resultant waste. The work was initiated after the necessary consent had been obtained.

Unfortunately, decontamination work reduces the dose rate by only about 50% on average. Naturally, the long-term goal of reducing the dose rate to below 1 mSv/y could not be achieved in highly contaminated areas, a fact that was widely criticized in the media. Evacuees were also discouraged by the fact that they were unable to return home even after the evacuation orders had been lifted. With respect to this issue, an IAEA investigation team that was invited to evaluate decontamination projects in 2013 made the encouraging claim that those involved in decontamination work should not be obsessed with this long-term target of 1 mSv/y [3)]. Substantive dose measurements were later conducted using personal dosimeters in Nihonmatsu and Date. The resultant measured dose rates were found to be about half the levels estimated based on air dose rates. To verify claims made by experts from the ICRP, the author evaluated the country-averaged annual exposure dose rates caused by natural radiation throughout the world and summarized the results in a graph. This graph was welcomed by residents of Fukushima Prefecture, who said, "We feel very relieved." When it was presented at the dialogue forum, though, this same graph was referred to as an excuse for not having achieved the long-term target [4)]. This claim made the author realize the limitations of his earlier activities, which prompted him to leave the Ministry of the Environment. Since then, he has engaged in discussions focused on the issue of reconstructing Fukushima with students by joining dialogue forums organized by a Senior Network of the Atomic Energy Society of Japan (AESJ). Through these activities, the author was able to learn how people outside Fukushima view the problems there. Based on the above experience, the following sections discuss problems related to decontamination and radiation.

II. Decontamination

1. Decontamination Technologies and Procedures

Initially, pilot decontamination projects were conducted by the Japan Atomic Energy Agency (JAEA) and Japan's Self-Defense Forces to confirm the decontamination technologies alongside the volunteer decontamination work conducted in Date and Fukushima. The Ministry of the Environment developed decontamination guidelines based on the outcomes of these pilot decontamination projects [5)] to standardize measures for later decontamination projects. More details on the decontamination technologies and procedures can be found on the website of the Decontamination Information Plaza (current name: Environmental Regeneration Plaza; http://josen.env.go.jp/plaza/).

It is worth mentioning the trouble that experts experienced when dealing with uninvited guests at the Decontamination Information Plaza and lecture meetings who insisted that the decontamination work was unacceptable as the radioactive materials were simply relocated as a means of transferring the contamination rather than being completely removed. Furthermore, residents and contractors complained about the decision of the Ministry of the Environment to suspend the pressure washing of roofs when the dose rates were reduced by rain washing away radioactive materials over time. The ministry revised [6)] the guidelines to incorporate new findings and better methods that had been devised based on the experience gained from earlier decontamination work. A comprehensive review of the decontamination projects was also conducted.

2. Decontamination Targets

According to the ICRP guidelines, decontamination work is conducted with the aim of achieving the long-term target for the exposure dose rate of 1 mSv/y, which is the dose limit for ordinary people. However, it is recommended that an actual operating target be assigned at an appropriate level of between 1 and 20 mSv/y [7)].

The volunteer decontamination work in Date that the author participated in was conducted with the aim of achieving the upper limit for the annual additional exposure dose rate of 5 mSv/y in accordance with the instructions issued by Mr. Shunichi Tanaka, who headed the Nuclear Regulation Authority from 2012 to 2017. Around October 2011, many spots with a dose rate that exceeded 5 μSv/h were found around Ryozen, a town in Date where the accumulated dose was estimated to be 20 mSv for one year after the accident and was designated as a recommended evacuation point on June 30. The decontamination work was conducted by selecting areas with a measured dose rate of more than 1 μSv/h at a height of 1 m above the ground. The grass was mown, and topsoil in places with a dose rate of more than 3 μSv/h was scraped off. Around a hut without a front-covered gutter, the rain fell directly from the roof to the ground, making deep holes. As a result, hot spots with a dose of 10 μSv/h formed around the holes. The doses at these spots could be reduced by digging down about 30 cm. Finally, the scraping of topsoil was limited to a thickness of 5 to 10 cm since digging deeper would only increase the amount of soil waste. Uncontaminated soil was used to provide a shield against radiation. Of course, the decontamination work for houses and trees that needed to be carried out at elevated locations was outsourced.

With respect to the target areas for full-scale decontamination, the Ministry of the Environment initially offered to cover the decontamination expenses for areas with an annual dose of over 5 mSv/y. On April 30, 2011, Mr. Toshisou Kosako resigned from his post as Special Advisor to the Cabinet over the issue of restoring school environments [8)]. At that time, he did not clearly indicate the reference level for the decontamination of living environments. This led to surging support for a long-term goal of limiting the dose rate to 1 mSv/y. Accordingly, Mr. Yuhei Sato, Governor of Fukushima Prefecture, requested that the Japanese government provide a budget that would also cover the decontamination of areas with a dose rate of between 1 and 5 mSv/y. His request was approved by the former Minister of the Environment, Mr. Goshi Hosono [9)]. The selection of decontamination targets was left to the judgment of the municipalities. As mentioned earlier, Date maintained a target of 5 mSv/y for its volunteer decontamination work in consideration of the natural decay of cesium and with the intention of reducing the amount of waste, which was clearly described in their decontamination plan. In contrast, most municipalities conducted decontamination work in areas with a dose rate of more than 1 mSv/y. In practice, they conducted radiation monitoring and selectively decontaminated places with a dose rate of 0.23 μSv/h or more. Extensive area decontamination work was performed in the special decontamination area where the government conducted decontamination work directly, but selective decontamination work is generally being performed in a similar manner to that adopted by the municipalities.

3. Impact of the Budget Allowance for the Decontamination of Areas with a Dose Rate of Between 1 and 5 mSv/y

The policy shift to cover the costs of decontaminating areas with a dose rate of between 1 and 5 mSv/y inevitably increased the budget by a few trillion yen. Efforts to achieve this lower dose limit resulted in the increased amount of decontamination waste being left on site due to the difficulty involved in securing enough space for its temporary storage.

Concerns over a higher dose rate than the long-term target of 1 mSv/y increased the number of refugees from Fukushima Prefecture. Furthermore, people who tried to achieve the target of 5 mSv/y have lost a sense of accomplishment. The air dose rate target of 1 μSv/h was very easy to understand for measurements, but the target of 0.23 μSv/h is quite complicated and baffling. Moreover, when 1 μSv/h was the target, places where it was only necessary to sweep away fallen leaves and remove weeds, for example, needed the further removal of topsoil in order to achieve 0.23 μSv/h. Consequently, people felt that they could not do it by themselves, so they asked the national government or local government to handle it. The feelings of residents who thought that they could do it themselves and wanted to complete the decontamination work in a hurry also cooled, and the progress made in the decontamination work suffered as a result.

People who initially considered returning to their homes began to feel that they must wait until the dose level has dropped below 1 mSv/y. Even some local leaders began to insist that they were unable to lift the evacuation orders because a return is impossible until the dose level falls below 1 mSv/y.

It is quite reasonable that Ms. Marukawa, Minister of the Environment, objected to the policy change made by former Minister Hosono, taking into account issues such as the enlargement of the budget. In the discussion held in the Diet, however, the essential issue was not discussed and her incidental comment that the "change to the decontamination target was made without scientific basis" was attacked as being wrong, forcing her to withdraw her statement. Given that the radiation dose in Date City, which was decontaminated with a target of more than 5 mSv/y, has now almost reached the long-term target of 1 mSv/y, it can be said that the ministry's original policy was not wrong.

4. Decontamination Results and Post-Decontamination air Dose Rates in Major Cities

Table 1 shows the progress in decontamination work that municipalities made in September and October 2015 [10]. It has almost been finished outside Fukushima Prefecture, and 70% of all residential areas in Fukushima Prefecture have been completed. The decontamination work led by the national government was completed for the residential areas in Tamura, Kawauchi, Naraha, and Okuma, followed by those in Katsurao, Kawamata, and Iitate. The remaining work will be completed by the end of this fiscal year.

Thanks to this decontamination work, the air dose rates caused by radioactivity have dropped. According to airborne monitoring [11] conducted on September 29, 2015 (the results can be viewed by accessing https://radioactivity.nsr.go.jp/ja/list/362/list-1.html), the air dose rate 1 m above the ground surface has been reduced to 1 mSv/y extensively throughout Fukushima Prefecture.

Table 2 shows the air dose rates measured at some of the monitoring posts in Fukushima Prefecture [12] (https://www.pref.fukushima.lg.jp/sec/16025d/kukan-monitoring.html). In around 2012 to 2014, fears were raised that the target air dose rate of 0.23 μSv/h would not be achieved. Today, the target of 0.23 μSv/h, which corresponds to 1 mSv/y, has been achieved in most parts of the Nakadori region of Fukushima Prefecture. The air dose rates in most parts of Date are close to 0.1 μSv/h, except for the Shimooguni Assembly Hall (Ryozen), which has a dose rate of 0.24 μSv/h. The same trend can be observed in Iwaki, Hirono, Soma, and other nearby municipalities in Hamadori. In addition, almost all of the decontamination special areas under the direct control of national government, Tamura, Kawauchi, Naraha, and Kawamata have dose rates of less than 0.23 μSv/h. Currently, about 90% of Katsurao, where decontamination work is underway, about 75% of Minamisoma City, and about 25% of Tomioka and Iitate have dose rates of less than 0.23 μSv/h. Futaba, Namie, and Okuma, which have many difficult-to-return areas, have also cut their dose rates to 0.23 μSv/h, as is the case in the Okawara area, where decontamination work has been completed. However, although most of the monitoring posts are located at public facilities, their values are representative values. Other than that, there are places with high doses, but they do not significantly exceed 0.23

Table 1 Progress made in municipality-led decontamination work [1]

	Inside Fukushima Prefecture (as of the end of October 2015)	Outside Fukushima Prefecture (as of the end of September 2015)
Public facilities	Approx. 90%	Almost completed
Houses	Approx. 70%	Almost completed
Roads	Approx. 40%	Approx. 90%
Farmland, pastures, etc.	Approx. 80%	Completed
Forests around houses	Approx. 50%	Completed

Table 2 Changes in air dose rates at the main monitoring posts

Post location		Apr. 29, 2011	Nov. 7, 2014	Feb. 3, 2016
Date	City Office	1.25, 1.23	0.23, 0.21	0.17
Fukushima	Health and Welfare Office for North Fukushima	1.58	0.24	0.19
Kawamata	Town Office	0.73, 0.75	0.16, 0.16	0.09
	Yamakiya Fire Service Center	(~3.0)	0.68, 0.68	0.24
Nihonmatsu	City Office	1.39, 1.44	0.25, 0.26	0.20
Tamura	Tokiwa Administrative Office	0.26	0.10, 0.09	0.08
Koriyama	Government Office Complex	1.53	0.13	0.11
Shirakawa	Government Office Complex	0.64	0.09	0.07
Aizuwakamatsu	Government Office Complex	0.18	0.06	0.06
Minamisoma	Government Office Complex	0.54	0.11	0.08
Hirono	Shimokitaba Assembly Hall	(~0.8)	0.11, 0.11	0.07
Iwaki	Government Office Complex	0.27	0.07	0.07

Note: Air dose rates in units of μSv/h

μSv/h.

The numerical value obtained by multiplying these air dose rates by five provides an estimate of the annual amount of exposure per mSv/y. Not only the Nakadori district, but also most of the residential areas in the area where municipal decontamination work is being carried out in the Hamadori district have dose rates of less than 1 mSv/y. With respect to the decontamination results for the special decontamination areas [12], more than half areas in Tamura, Naraha, and Kawauchi, where decontamination work was completed at an early stage, also have dose rates of less than 1 mSv/y, and even at their highest, the actual amount of exposure as measured with a personal dosimeter should be less than 1 mSv/y. The Okawara area, where the decontamination of Okuma was carried out, has a dose rate of around 1 mSv/y. The decontamination of residential areas in Katsurao, Kawamata, and Iitate has also been completed, and the post-mortem monitoring of each area is being carried out.

Of course, high doses exceeding 20 mSv/y of additional exposure can be seen in difficult-to-return areas. Decontamination plans have not yet been formulated for these difficult-to-return areas. In addition, the results of airborne monitoring show that some parts of forest area of Nakadori has a dose rate of several mSv/y. These are future issues for environmental recovery.

III. Radiation Risk Communication

1. Purpose and Intended Targets

In Japan, about 40 years ago, the description of radiation education disappeared from the course guidelines produced by the then Ministry of Education, Science and Culture, and radiation education was no longer conducted. As a result, anxiety about radiation, which people were no longer familiar with, spread immediately when the nuclear accident happened. In addition, discriminatory remarks were made concerning the genetic effects of the accident due to a failure to understand the effects of radiation exposure, and the reputation of food from the affected areas has increasingly suffered. Furthermore, there has, for example, been opposition to the final disposal facility for designated waste containing more than 8,000 Bq/kg from the wide-area treatment of rubble and radioactive materials. This opposition stems from anxiety about radioactive materials as well as concerns about the harmful rumors.

In order to solve these problems, it is important to communicate the basic nature of radiation, its effects and remedies, and the current state of radiation to the public, not to mention people from the affected prefectures. This is known as radiation risk communication. For this reason, after the accident, various academic societies specializing in radiation, mainly in the disaster-affected areas, and the decontamination information plaza, which is jointly operated by Fukushima Prefecture and the Ministry of the Environment, dispatched radiation specialists to support radiation education in schools and to conduct lectures and deal with questions about radiation and decontamination for volunteers such as kindergarten teachers, public health nurses, and community associations. As a result, knowledge of radiation in Fukushima Prefecture's citizens has improved considerably.

Meanwhile, the author noted that university students tended to have an inadequate understanding of radiation and the realities in Fukushima during the various dialogues that he has conducted with them regarding nuclear energy and radiation since fiscal 2014. For instance, they expressed surprise when the author mentioned that local newspapers in Fukushima and neighboring prefectures still report the local radiation doses and that Fukushima Prefecture keeps contaminated food products away from the marketplace by reporting the results of radiation inspections of food products on the market. This perception gap is presumably a source of harmful rumors and concerns over the stigma associated with them.

To dispel harmful rumors, radiation risk communication is vital not only for the affected communities themselves, but also for people from other areas.

The education provided to pupils at elementary and junior high schools is quite effective as younger people can generally absorb information about radiation more flexibly. Kindergarten students at a preschool in Fukushima gave the author an eye-opening experience when he discovered that they understand that our world is made up of many substances and that it has been bombarded by radiation ever since the beginning of the universe. Therefore, the benefit of using learning aids about radiation that are based on the target age group is questionable. Such learning aids should be organized according to levels of understanding.

2. Health Impact of Low-Dose Exposure

In radiation risk communication, the impact of low-dose exposure and the risks posed by the additional exposure to 1 mSv/y of radiation are matters of the greatest concern. The author and his colleagues have studied the latter and compiled relevant materials [13]. People generally have an annual exposure limit of 1 mSv. The corresponding risk coefficient is estimated to be 4.5×10^{-7} based on the epidemiological findings regarding atomic bomb survivors from Hiroshima and Nagasaki that cancer mortality increases by 0.5% for every 100 mSv if we assume that the radiological impact is proportional to the exposure dose. This figure is two orders of magnitude lower than the risk coefficient of 5.9×10^{-5} for deaths from motor vehicle accidents. In fact, it is comparable to the risks normally associated with the use of railways.

Meanwhile, ICRP experts proposed a comparison of the exposure dose rates from naturally occurring radiation. The author tried to present figures for parts of China, India, and Brazil

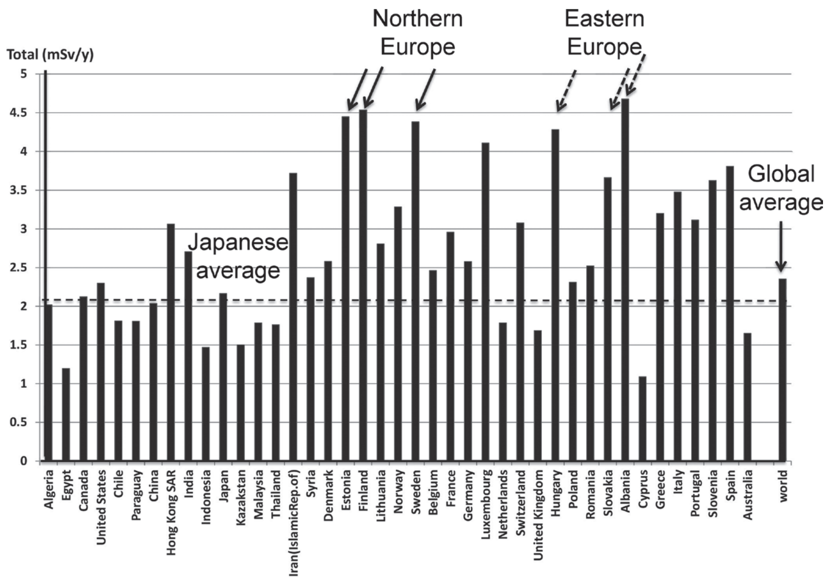

Figure 1 Annual exposure dose rate from naturally occurring radiation in different countries

that Japanese researchers had yet to explore, but the presentation of this information at the Decontamination Information Plaza did not gain much understanding. Changing his approach, the author compared the exposure dose rates from naturally occurring radiation in different countries based on data from the UNSCEAR 2000 Report[4, 13]. The results presented in **Figure 1** show that, due to greater exposure to radon, the dose rate levels for Northern and Eastern Europe (4–4.5 mSv/y) were about double that for Japan (2.1 mSv/y).

This finding is based on the average value for each country. An exposure of 5 mSv/y is quite likely considering the statistical variance of these values. A comparison with data obtained from the International Agency for Research on Cancer demonstrated that there is no correlation between the exposure dose and cancer incidence[14]. It was thus concluded that exposure to anything comparable to naturally occurring radiation does not affect cancer incidence or that the impact is statistically inconclusive.

3. Exposure in Fukushima

What people in Fukushima worry most about is their exposure immediately after the accident. According to a basic survey of about 450,000 people in Fukushima Prefecture[15], only 2% of people had an external exposure that exceeded 5 mSv in the four months after the accident, and 94% of them had one of 2 mSv. In addition, only 12 people had an external exposure that exceeded 15 mSv, and the maximum was 25 mSv.

Hirosaki University measured thyroid doses from exposure to iodine-131, which has a half-life of 8 days. The estimated maximum dose was no more than 100 mSv[16]. In the Belarusian city of Gomel, however, 3,400 children aged under seven were reported to have been exposed to a high-level dose of between 2,000 and 40,000 mSv[17]. Thyroid exposure in Fukushima was lower than that in Belarus by two orders of magnitude. Hence, cancer incidence is considered much less likely.

The radiation dose received by people in Fukushima is equal to the average natural radiation exposure in Japan plus an additional exposure caused by cesium. For example, the reported value for Kawauchi village in June 2014 immediately after decontamination was 4.1 mSv/y, even if the natural radiation exposure is added to the average value of 2.0 mSv/y. (Of course, the majority now have a dose rate of less than 1 mSv/y.) Figure 1 shows that this is almost the same as receiving it in Northern Europe and Eastern Europe.

4. Radiation Exposure from Food Intake and Food Standards

In terms of internal radiation exposure from food intake, it is important to note that the average Japanese male has 7,000 Bq of radioactive material, potassium-40, from food intake and that fish consumption results in an exposure of 0.98 mSv from polonium-210 and other radioactive materials.

Fortunately, food contamination of food products from Fukushima by radioactive cesium is rare thanks to the decontamination of and improvements to farmland. Measurements conducted using whole-body counters recorded a dose of no more than 1 mSv among 99.99% of roughly 250,000 residents in Fukushima Prefecture. The highest dose of 3 mSv was noted for two individuals [15]. International rumors about food products from Fukushima and Japan in general could be largely dismissed if the Japanese government communicated this fact to the world more decisively.

Importantly, other countries have imposed import restrictions based on the misunderstanding that many Japanese food products have been contaminated. This misunderstanding was caused by the assumption of a food contamination rate of 50% by the Food Safety Commission in an attempt to limit the lifelong exposure of the public to 100 mSv at their own discretion if they set rigorous standards such as a limit of 100 Bq/kg. In reality, only 2.5% of the food was contaminated with a dose that exceeded the provisional threshold by the time Ms. Komiyama, the Minister of Health, Labour and Welfare, advised that a new standard should be set to reduce the limit for the annual internal exposure dose from 5 mSv to 1 mSv. An assessment of internal exposure demonstrated an annual dose of 0.019 mSv [18] in Fukushima Prefecture, which is two orders of magnitude lower than the advised level of 1 mSv/y. This provisional standard was considered adequate. However, the new standard led to demands for an even more stringent standard due to the damage caused to the reputation of food products from Fukushima Prefecture and drove residents with small children to evacuate from the prefecture. Meanwhile, the European Commission adopted the following three-pronged standards: 1,000 Bq/kg for food from member countries as recommended by the Codex Alimentarius Commission; 600 Bq/kg for food products from areas affected by the Chernobyl Accident; and the new Japanese standard for food from Japan.

Recently, a proposal has been made to move away from such a fragmented set of standards and establish a unified international standard instead. Japan should take this opportunity.

IV. Conclusions

In this commentary, we discussed decontamination with the aim of recovering from the environmental pollution caused by the nuclear plant accident, which was triggered by the tsunami that occurred following the Great East Japan Earthquake, and the radiation risk communication necessary to facilitate a return of residents in the future.

In terms of decontamination work, we discussed what the decontamination target areas and values were, and most of the work was conducted for a dose rate of 1 mSv/y or more. As a result, it was found that the long-term target of 1 mSv/y was achieved in many areas of Fukushima Prefecture, except for residential restricted areas and difficult-to-return areas. On the other hand, it should be noted when determining the decontamination policy in the future that Date, which is targeting the decontamination of areas with a dose rate of 5 mSv/y, was able to achieve a dose rate of 1 mSv/y, including the specified evacuation recommendation point of 20 mSv/y.

Radiation risk communication described 1 mSv/y as a level that could be accepted by the public with respect to radiation risk, and revealed that exposure to natural radiation in Northern Europe and other countries is 5 mSv/y. This matter seems to provide a measure for judging radiation exposure. In addition, the public seems to have developed a good understanding through communication in the form of public relations magazines and the lectures that have been held for the people of Fukushima Prefecture so far. However, given that there are still about 100,000 evacuees in Fukushima Prefecture and that their return is not progressing, the author cannot help thinking that there is still a lack of communication. The problem is that the cancellation of evacuation orders has been delayed. This is because there are only two types of conditions for the cancellation of evacuation orders: 20 mSv/y as the evacuation order condition and 1 mSv/y as the long-term target. Of course, the cancellation of evacuation orders is applied taking into account improvements to the living environment, such as improvements to infrastructure and shops, but the importance of radiation is high. The author would like to propose that the level accepted by residents be a reference level for considering the cancellation of evacuation orders and that this level should be set to 5 mSv/y, which is what the exposure to natural radiation is in Europe. In addition, if a special guest in an evacuation order release preparation area can measure in advance the amount of exposure to be considered by using an individual dosimeter, the real dose measured using this individual dosimeter is desirable. However, if this is not possible, an evaluation value based on the air dose rate can be used. It is also expected that this reference level of 5 mSv/y will be considered in the decontamination work scheduled for forests and difficult-to-return areas going forward.

With regard to the disposal of decontamination waste, which is not mentioned in this commentary, the author proposes efforts and concrete plans to gain the understanding of residents because the burden on the final disposal site can be reduced in the future by using the waste as the foundation for roads and seawalls, taking into account the fact that the radiation dose decreases and cesium is strongly adsorbed into the clay crystals contained in the soil and does not dissolve in water. With regard to the construction of a final disposal site for designated waste, the author proposes that we aim to reach an agreement at a stakeholder dialogue meeting, which has been successful in Europe and the United States, in order to realize this kind of policy, rather than a briefing session between government offices and residents as before.

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What Factors Determine Public Acceptance for Nuclear Power Stations

−Learning from Public Survey in Area of Hamaoka Power Station−

Tokoha University, **Ryuzo Yamamoto**

Papers from other countries on public acceptance of nuclear power and a survey that we conducted in four cities near the Hamaoka Nuclear Power Plant have demonstrated that people interested in the issues of energy supply and climate change recognize more of the benefits of nuclear energy. The level of public acceptance depends on the timing and country. Analysis of such differences will probably offer clues on how to obtain a deeper understanding of nuclear energy among the public. Furthermore, analysis of the ways in which people perceive the benefits of nuclear energy and how they compare these benefits against the risks will enable us to identify ways of helping them obtain a deeper understanding of nuclear energy.

KEYWORDS: Hamaoka Nuclear Power Plant, climate change, energy security, energy price, public opinions, social acceptance

I. Introduction

An energy supply policy pursues the reliable and safe delivery of competitive, environmentally friendly energy and power to consumers. Public opinion on nuclear power naturally depends on how well the policy goal of the 3Es (economics, environment, and energy security) plus S (safety) is achieved.

One advantage of nuclear energy is that it can economically and reliably provide consumers with affordable electric power with marginal carbon emissions. However, the perceived disadvantages are also great due to the risk of severe accidents that could lead to radiation leaks as well as problems involving the disposal of nuclear waste. As such, public opinion varies depending on how these advantages and disadvantages are evaluated in different countries at different times.

For instance, people with a strong interest in global warming and climate change tend to be more supportive of nuclear power. Furthermore, the emergence of any energy security challenges is expected to increase the share of those in favor of nuclear energy. The most desirable form of education on energy can be explored by examining the relationship between the level of public acceptance of nuclear power and the level of interest in energy policies.

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In last month's commentary (page 191–198 of this volume) we reported the results from a questionnaire survey conducted in four cities near the Hamaoka Nuclear Power Plant, which is located in Shizuoka Prefecture. The survey also examined the correlation between the level of interest in the four energy policy issues and the level of acceptance of nuclear power among respondents. These findings are analyzed to consider what factors require particular emphasis in educational activities related to energy.

II. Why Does Public Acceptance of Nuclear Power Fluctuate?

At times, public acceptance of nuclear power can fluctuate significantly. For instance, the share of people in favor of nuclear energy dropped in many countries after the Chernobyl Accident and the Fukushima Daiichi Nuclear Accident. In contrast, support for nuclear energy strengthened rather than weakened in the United Kingdom. What influences public acceptance? This section reviews earlier studies to examine the varying reasons of public acceptance of nuclear energy in different times and countries.

1. Changes in Public Opinion Over Time

American people are generally in favor of nuclear energy. Except for the temporary reversal that occurred after the Three Mile Island Accident, more Americans have indicated that they are in favor rather than against it since the early days of nuclear power until the survey last year.

Professor Michael Golay of the Massachusetts Institute of Technology divides the history of nuclear power in the United States into the following three phases [1)].

1) Initial optimism during the first half of the Vietnam War up to 1968 under the Eisenhower and Kennedy administrations
2) Doubts, criticism, and pessimism after the Vietnam War
3) A tailwind for nuclear energy during the economic expansion from the early 1990s

The balance between support and opposition to nuclear energy in each of the phases reflects the prevailing economic and social conditions. Conceivably, the balance may also have been influenced by the organizational performance of stakeholders in the nuclear sector. Professor Golay excludes any technological influence on public opinion given that the equipment used in nuclear power generation has not evolved much throughout the three phases. The professor summarizes these three phases as described below.

From the first half of the Vietnam War until the mid-1960s, the American public was highly appreciative of nuclear power. The idea of using nuclear aircraft and rockets was widely supported, and universities were eager to set up their own nuclear research reactors. In fact, power utilities without nuclear power plants were considered backward. The order placement and planning stages for most currently operational plants date back to this phase.

During the economic stagnation and uncertainty that followed, from the intensification of the Vietnam War in the mid-1960s through to the early 1990s, US politics was caught up in disagreements over the future of the country. Public opinion on nuclear energy was also influenced by this uncertainty. The risk of nuclear accidents and issues concerning nuclear waste disposal had been pointed out even before the Three Mile Island Accident.

The robust economic growth that was experienced from the early 1990s bolstered national confidence and optimism, which helped dispel concerns over nuclear energy to some extent.

The steady enhancement of plant capacity utilization—typically by 20%—also tilted public opinion in favor of nuclear power. According to a Gallup poll conducted in 1994, 57% of respondents in the United States were in favor of nuclear power while 37% were opposed.

2. Changes in Public Opinion in Different Countries

In the European Union, 15 member countries operate 131 nuclear power reactors, thereby covering 27% of their power needs. According to a survey published in 2014, energy is not a high-profile issue. Only 14% of respondents indicated an interest in energy issues, as compared to unemployment (64%), crime (36%), and health insurance system (30%) [2). Another possible reason for the considerable variations in public opinion among different countries may be differences in the ways that surveys are conducted or questions are framed in surveys.

For instance, people are more likely to respond that nuclear energy is necessary if the question is asked in relation to the response to global warming. When asked to choose between the continued operation and additional construction of nuclear power plants, more respondents will shy away from the latter, thereby diminishing the share of pro-nuclear responses. The European Nuclear Energy Forum asks the same questions to clarify the varying degrees of public support toward nuclear energy among major European countries.

These differences can probably be ascribed to cultural backgrounds in the respective countries and public attitudes toward energy security, and global warming and climate change. The circumstances in some European countries are presented here to consider the reasons behind the varying levels of public acceptance of nuclear energy.

Finland has constructed the Onkalo (the Finnish word for "cave") disposal site for high-level waste. In a survey conducted in 2014, 41% of respondents supported nuclear power, while 24% were against it. Nuclear power is widely discussed in Finland. Finns are known to be pragmatic, and they probably consider it risky to depend on Russia for their energy supply.

France covers more than 70% of its power needs with 58 nuclear power reactors, the second largest number after the United States. The experience of the 1973 oil crisis prompted France to adopt nuclear power to ensure a secure energy supply. Educational activities related to energy issues are being conducted extensively for French citizens. Study tours of nuclear power plants are organized in earnest for schools and workplaces. When asked how they regard this considerable dependency on nuclear energy for their power supply, the majority consistently responded that it brings advantages to France until this view was suddenly reversed when the majority recognized more disadvantages in 2012 in the immediate aftermath of the Fukushima Nuclear Accident. In the next survey conducted in 2013, however, pro-nuclear views prevailed again, with 48% of respondents viewing nuclear power as advantageous against 36% viewing it as disadvantageous.

In another survey conducted in the United Kingdom by the Department of Energy and Climate Change in March 2014, 42% of respondents were in favor of nuclear power, 20% were opposed, and 38% had no opinion. The reasons for this high public acceptance of nuclear energy include a high level of interest in energy security and climate change among British people, who are concerned over the diminishing production of domestic coal as well as petroleum and natural gas from the North Sea. Both the government and citizens seem to recognize that renewable energy alone cannot address these issues adequately.

Prompted by the Fukushima Daiichi Nuclear Accident, Germany officially decided in August 2011 to shut down eight nuclear power reactors that had begun operating before 1980. Nine nuclear power reactors that are currently still in operation will also be shut down by 2022. In a survey conducted in April 2014, 52% of respondents opposed the idea of revising the country's energy policy of decommissioning nuclear power plants for the sake of energy security. In other words, more than half of the nation supports the current government policy of opting away from nuclear energy.

Public opinion seems to vary in different countries due to differences in their understanding of issues related to energy security, climate change, energy prices, and accidents at nuclear power plants. In the next section, we trace changes in public opinion associated with the Fukushima Daiichi Nuclear Accident to examine how public opinion is influenced by the public's level of understanding of energy policies.

3. Impact of the Fukushima Daiichi Nuclear Accident on Public Opinion

From June to September 2011, the BBC conducted a public opinion poll on nuclear and renewable energy in 23 countries, including 12 countries with nuclear power plants [3)]. An earlier survey was conducted with eight countries in 2005.

In 2011, the following 12 countries with nuclear power plants took part in a survey on nuclear power: Brazil, China, France, Germany, India, Japan, Mexico, Pakistan, Russia, Spain, the United Kingdom, and the United States. In total, 22% of the respondents believed that new plants should be constructed, 39% favored continuing the operation of existing plants but not constructing any new ones, and 30% thought that existing plants should be shut down immediately.

Support for the construction of new nuclear power plants varies greatly from one country to the next. The high level of support found in China (42%), Pakistan (39%), the United States (39%), and the United Kingdom (37%) is in stark contrast to the less than 10% support found in Japan, Germany, Russia, and Spain.

Figure 1 compares opinions on the future of nuclear power in 2005 and 2011 according to the results of a survey conducted in five countries (Germany, France, the United Kingdom, the United States, and Japan). Calls for an immediate shutdown grew louder in Germany, France, and Japan, but weakened in the United Kingdom and United States despite the fresh memory of the Fukushima Daiichi Nuclear Accident.

This weaker opposition to nuclear energy in the United Kingdom and the United States is probably due to the majority believing that the perceived benefits outweigh the perceived risks, even after the accident in Fukushima. A large number of respondents from China and

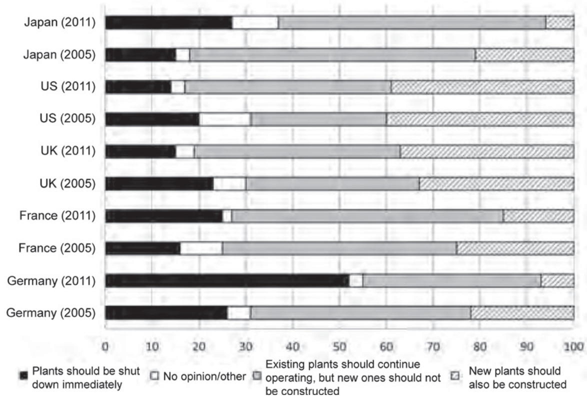

Figure 1 Changes in public opinion on nuclear power
Source: BBC World Service Poll, November 2011

Pakistan support the construction of new plants, and this is probably because of the perceived benefits of nuclear energy against the backdrop of an expected surge in energy demand.

So, why do the British public and the American public perceive greater benefits and endorse nuclear energy more than people in other countries do? In the next section, we consider this question based on public opinion surveys conducted in these two countries.

III. Perceived Benefits of Nuclear Power

Nuclear power improves a country's energy self-sufficiency and makes electricity prices more stable. Furthermore, this low-carbon source of power also helps curb climate change. In spite of the risks associated with severe accidents and waste disposal, nuclear energy is employed by many countries because the risks are outweighed by the benefits. Nonetheless, the perceived benefits and risks vary depending on cultural backgrounds and other factors among different countries.

1. British Sensitivity to Climate Change

Most of the British public have an interest in the issues of climate change and energy security. In addition, many think that renewable energy sources alone are not enough to tackle climate change. Hence, nuclear energy is widely supported there, even after the Fukushima Nuclear Accident[4].

Figures 2 and **3** show British perceptions of nuclear energy and climate change, respectively. The slight drop in the share of people who are concerned about climate change observed from 2012 to 2013 is probably due to an increase in the number of people who accept some of the arguments presented by global warming skeptics. This drop has also chipped

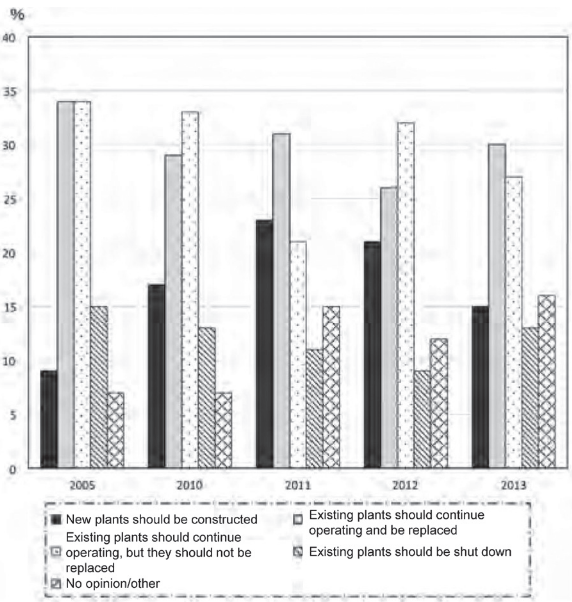

Figure 2 British public opinion on nuclear power generation[4]

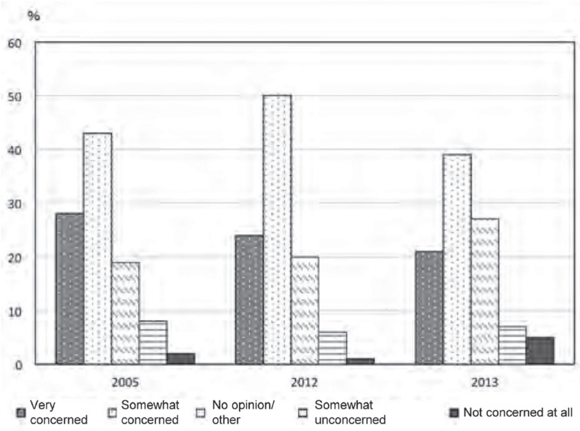

Figure 3 Are you concerned about climate change? [4)]

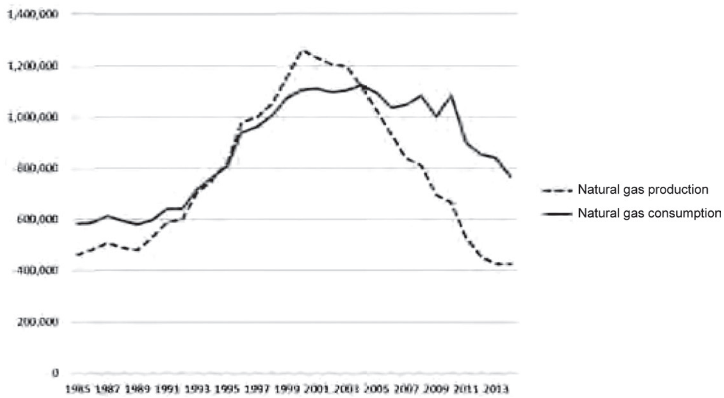

Figure 4 Natural gas production and consumption in the United Kingdom
Source: British Department of Energy and Climate Change

away at some of the support for the construction of new nuclear power plants.

In a survey conducted in 2013, 37% of the respondents believed that the perceived benefits of nuclear power were greater than the perceived risks, 29% believed that the reverse was true, and 20% believed that they were balanced. The benefits of nuclear power seem to be recognized by most citizens in the United Kingdom. Indeed, 47% of them agree with the construction of new plants if doing so helps to address climate change, while 24% are opposed. Similarly, 52% agree if doing so helps to enhance energy security, while 22% are opposed. One possible reason for this is the reduced natural gas production in the North Sea and the resultant decline in the country's energy self-sufficiency as shown in **Figure 4**.

2. American Sensitivity to Energy Prices

In March 2016, a Gallup poll revealed for the first time that more than half of American respondents were opposed to nuclear energy [5)]. Public acceptance of nuclear power stood at around 57% even in a survey conducted in 2012 in the aftermath of the Fukushima Daiichi Nuclear Accident. In fact, the level of support remained the same as that observed in the

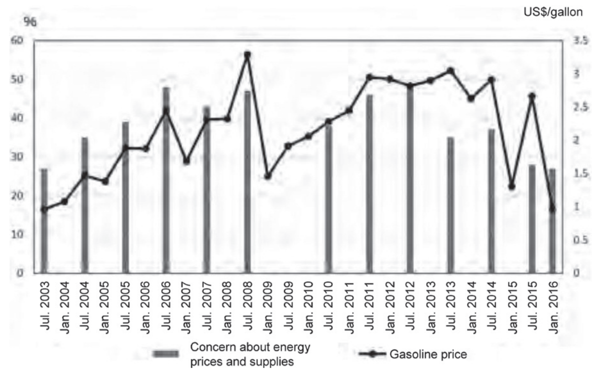

Figure 5 Gasoline prices and concern about energy supplies

Note: No survey was conducted in 2009. Even if a set of results is labelled "July," it does not necessarily mean that the survey was actually conducted in July.

Source: Gasoline prices according to the US Energy Information Administration and percentage of concerned respondents according to a Gallup poll

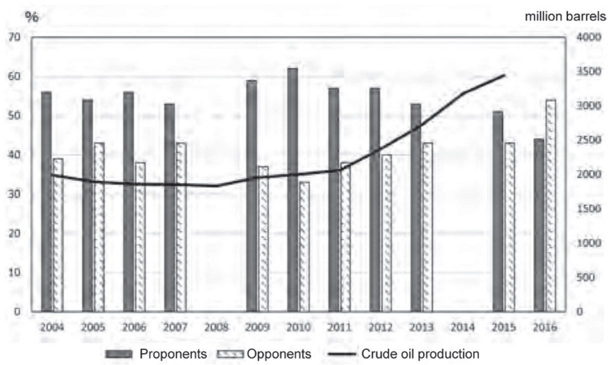

Figure 6 Crude oil production and changes in public acceptance of nuclear energy

Note: No surveys were conducted in 2008 and 2014.

Source: US Energy Information Administration and Gallup

previous survey before the accident. Given this, it is clear that the subsequent decline in acceptance was not due to concerns about severe accidents.

Another public opinion survey on energy issues that was conducted around the same time revealed a record low percentage of respondents concerned about energy supplies and prices. The factors underlying this are increases in shale oil and gas production in the United States along with a continuous decline in the oil price. Thanks to this shale oil production, the United States overtook Saudi Arabia to become the world's top oil producer. The United States also became the top producer of shale gas. In February this year (2016), exports of liquefied natural gas began for the first time in a state other than Alaska.

The shale revolution has turned the United States into the top producer of oil and natural gas. Combined with the declining oil price, this development has helped to defuse concerns about energy security. As shown in **Figure 5**, the declining gasoline price in the United States has helped Americans shake off the sense of crisis that they had over energy supplies. **Figure 6**, which compares changes in domestic oil production and public acceptance of nuclear energy in the United States, implies that fading concerns over energy supplies and prices tend to reduce public support for nuclear energy.

Table 1 Are nuclear power plants necessary to ensure a reliable power supply?

	Knew about additional fuel costs	Did not know about additional fuel costs	
Responses	3026	4333	
Definitely necessary	22.7	9.7	%
Somewhat necessary	28.2	30.1	
Somewhat unnecessary	17.5	23.6	
Definitely unnecessary	29.3	29.4	
No opinion	2.3	7.1	

Table 2 Are nuclear power plants necessary for curbing global warming?

	Knew about Japan's emissions reduction target	Did not know about Japan's emissions reduction target	
Responses	3963	3397	
Definitely necessary	15.4	9.5	%
Somewhat necessary	27.1	25.1	
Somewhat unnecessary	22.0	26.5	
Definitely unnecessary	30.8	27.1	
No opinion	4.7	11.7	

3. Awareness among Communities Near the Hamaoka Nuclear Power Plant

The survey that we conducted in four cities located near the Hamaoka Nuclear Power Plant was designed to examine if the level of support for nuclear power varies depending on interest in energy security, fuel prices, and climate change.

In this survey, questions were also asked to determine whether the respondents had any knowledge of matters such as the level of energy self-sufficiency in Japan, the 2015 United Nations Climate Change Conference (COP 21), Japan's greenhouse gas emissions target for 2030, the additional fuel costs, and increased electricity prices.

Most respondents knew about COP 21, energy self-sufficiency, and the increase in electricity prices. However, the responses were roughly split in two with respect to whether they knew about Japan's emissions target and the necessary additional fuel costs. The responses were analyzed to determine how the respondents' knowledge or ignorance of these two issues related to global warming and energy supplies influenced their acceptance of nuclear power.

The results summarized in **Tables 1** and **2** demonstrate that respondents with a greater interest in the issues of energy supplies and climate change tend to favor nuclear power. As mentioned in the previous commentary, negative views on nuclear power may be more pronounced due to the composition of respondents not reflecting the actual age structure of Japan's population. Adjusted by age, the share of responses in favor of nuclear power would increase, reflecting their relatively greater interest in these issues.

IV. For Building a Deeper Understanding of Nuclear Power

The results of various surveys on nuclear power conducted in the United Kingdom and the United States as well as one conducted near the Hamaoka Nuclear Power Plant demonstrate that the level of understanding of nuclear power is strongly correlated with knowledge of issues related to energy security, energy prices, and climate change.

Promoting a deeper understanding of issues concerning energy supplies, and climate change and global warming clearly enhances public acceptance of nuclear power. Furthermore, as shown by the results of a survey conducted in the United Kingdom, for example, climate change skepticism can reduce support for nuclear power. Instead of stressing a specific benefit, we need to consider all of the advantages of nuclear energy in a comprehensive manner.

The use of nuclear power ensures energy security, stabilizes energy and electricity costs, and curbs climate change. The risks posed by nuclear power are likely to be outweighed by the benefits and the resultant advancement of social welfare. Continuous engagement with citizens must be made to promote a deeper understanding of the benefits offered by nuclear power.

When this action is taken, particular attention must be paid to a couple of tendencies. One of these tendencies is that women around the world tend to oppose nuclear power. **Table 3** shows that the United States is no exception, with the share of American women who are opposed to nuclear power exceeding that of American men. A deeper understanding of nuclear power should be sought among women by providing them with explanations that have a particular emphasis on economic performance and the risk of accidents.

The other tendency, which is unique to Japan, is that the elderly tend to oppose nuclear power. In contrast, Table 3 shows that elderly people in the United States tend to favor nuclear power more than the younger age groups do. Given this, some creative thinking is required in relation to the way that explanations are offered to the elderly in Japan.

In the United States, direct communication from plant workers is also considered an important way of gaining public understanding of nuclear power. A sense of reassurance can be gleaned when people find plant workers to be trustworthy. It is important for workers from a wide range of age groups to demonstrate how they work, because some people reportedly get worried if they see only young workers who appear inexperienced in their eyes. Ingenuity must be continuously exercised to build public trust.

Table 3 American public opinion broken down by age group and gender

	In favor of nuclear power	Opposed to nuclear power
US total	57	40
Male	72	27
Female	42	51
Age 18–49	53	44
Age 50+	61	34

Source: Americans still favor nuclear power a year after Fukushima, March 2012

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Risk Communication on Health Effects of Low-dose Ionizing Radiation
–Practice of Community-Based Risk Communication–

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A new methodology of community-based risk communication was developed in cooperation with the local community by targeting the risks associated with the health effects of exposure to low-dose radiation after the Fukushima Daiichi Nuclear Accident. Before and after the study sessions that were conducted for three years as a joint pilot program with the citizens of Tsuruga, attitude surveys were conducted to analyze changes in the participants' knowledge, risk perceptions, and attitudes with respect to radiation, thereby validating the effectiveness of the methodology used for community-based risk communication. This commentary examines community-based risk communication with reference to the matters discussed in the public forum on the health effects of exposure to low-dose radiation that was held in Ookayama in March 2016.

KEYWORDS: Risk communication, low-dose ionizing radiation, nuclear consensus building, public participation, health effects, community-based, social implementation

I. Introduction

The most pressing and long-standing issue that continues to stand in the way of the recovery and reconstruction efforts conducted since the Fukushima Daiichi Nuclear Accident is the health effects of exposure to low-dose radiation. We will not be able to overcome any possible future obstacles and restore public trust unless a greater understanding of radiation is fostered among the public.

The importance and urgency of risk communication were also pointed out in Chapter VI of the final report [1] published by the Government's Investigation Committee on the Accident at the Fukushima Nuclear Power Plant of Tokyo Electric Power Company.

After the accident, risk communication was conducted by the Ministry of the Environment (MOE), the Ministry of Education, Culture, Sports, Science and Technology (MEXT), the Consumer Affairs Agency (CAA), and numerous research institutes, learned societies, and other associations. Many briefing sessions and lecture meetings have already been held, and

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many materials on risk communication are available. In addition to lecture meetings for large audiences, interactive meetings are also held for relatively small groups. Research institutes, learned societies, and associations are also conducting training to produce radiation communicators.

Nonetheless, as indicated by the results from the latest attitude survey conducted by the CAA [2], public concern over the health effects of exposure to low-dose radiation has yet to be dispelled. Why is this?

Conventional communication about nuclear did not postulate a major disaster like the one that occurred in Fukushima. This method was developed with the aim of promoting public understanding of nuclear and gaining public acceptance in ordinary times based on the fundamental assumption that nuclear safety was assured. However, the method seems to have been employed in risk communication even after the Fukushima Daiichi Nuclear Accident.

The health effects of exposure to low-dose radiation can be roughly divided into the following: probabilistic effects and psychosocial effects.

To provide scientific evidence of the probabilistic effects, quantitative evaluations have been conducted by the ICRP and UNSCEAR to assess the risks associated with exposure to a dose of 100 mSv or more as well as in many other epidemiological studies. The psychosocial effects stem from the following factors: uncertainty concerning the abovementioned evaluations of the risks posed by low-dose exposure; a deterioration in the living, cultural, educational, and economic environments along with a fragmentation of the community following the evacuation; and public mistrust and anxiety due to a reduced level of trust toward the government and experts. Fear and anxiety concerning the radioactive contamination of food typically induce aversive behavior. It must be remembered that, for some people, this may progress even further and develop into radiophobia and a constant fear of a negative turn of events.

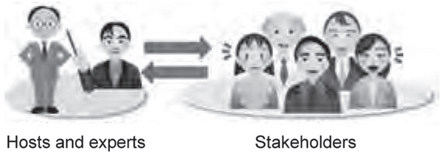
So, how can we communicate risk-related information in a scientifically sound manner? How can we handle uncertainties that cannot be validated exclusively by scientific means? How should psychosocial effects be taken into account? To address these questions, the author and his colleagues have developed a new methodology of community-based risk communication by working together with the local communities. The effectiveness of this methodology was validated in a pilot program conducted using study groups over the course of three years in Tsuruga, Fukui Prefecture, since it is the host municipality of a nuclear power plant. This commentary discusses how community-based risk communication can be practiced effectively in society while referring to the outcomes of the pilot program.

II. Community-Based Risk Communication

1. Definition of Community-Based Risk Communication

Community-based risk communication differs from conventional dialogues between the hosts and experts on one hand and the participants and other stakeholders on the other (**Figure 1** (a)). Instead, such communication is conducted among the stakeholders of a community in tandem with experts (Figure 1 (b)). In this context, a community consists of groups of local residents.

Participatory approaches are taken either through consultative bodies that are operated to build consensus on community development plans and waste management plans [3] or through committees that are formed by learned experts and citizens [4]. Dialog forums [5] are held to facilitate communication regarding radioactive waste.



(a) Conventional risk communication

(b) Community-based risk communication

Figure 1 Modes of risk communication

The author and his colleagues investigated various risk communication activities that had been conducted in the past. These activities included risk communication conducted by the MOE to address health concerns about radiation, risk communication conducted by the CAA to address the issue of food and radioactivity, and a study session conducted by the Committee on Program for Responding to Fukushima Daiichi Nuclear Accident of the Japanese Radiation Research Society to address the health effects of radiation. A practical methodology of community-based risk communication was designed with reference to the investigation of these precedents and a survey conducted with the residents of Tsuruga to determine their attitudes towards radiation and risk [6].

2. Characteristics of Community-Based Risk Communication

Residents share common or similar local settings in the community where they live. For this reason, they can perceive the risks that affect their community as their own problems. In other words, community members can be assigned a common challenge of seeking a solution through their joint efforts.

As mentioned at the beginning of this commentary, the conventional approach to risk communication tends to suffer from the problems listed below, as this form of communication was intended to gain public acceptance of nuclear in ordinary times based on the fundamental assumption that nuclear safe was assured.

- A patronizing and paternalistic approach is taken to “educate” and convince the “ignorant public.”
- Hosts tend to have the mistaken belief that the public can make proper judgements as long as the right information is provided (deficit model).
- Inappropriate risk messages are employed.
  A fear campaign and inappropriate comparisons with the risks of drinking, smoking, etc.
- Explanations of the impact of uncertainty, which forms the essence of risk, are inadequate.

For the above reasons, the following requirements were taken into account for community-based risk communication.

- Establish small study groups to facilitate the participation of local community members

Establish small groups of up to 15 members each to encourage local residents to play an active part in the discussions. Facilitate all participants to speak and share their thoughts. Encourage their continuous participation in at least five study sessions, because one to three sessions would not be sufficiently effective.

- Make arrangements to encourage voluntary participation

Even if people take an interest in the discussions, they will feel powerless if they are unaware that the outcomes of their sincere contributions to these discussions can make a difference. Accordingly, arrangements should be made to motivate them to participate in discussions repeatedly by appealing to their right to self-determination [i] and sense of self-efficacy [ii] in addition to their right to know.

In practice, learning materials for study groups are initially prepared by experts and then modified jointly with participants while incorporating input from stakeholders until they can genuinely accept the content. More specifically, residents are requested to engage in activities aimed at jointly creating a guidebook that is both acceptable to themselves and useful in providing explanations for residents in other communities.

- Explain the relevant logic in addition to providing information

Explain how people can make their own judgments on risks while also providing the relevant information. Risk literacy involves the transfer of risk-related information; it does not necessarily mean that people will voluntarily accept risks. Aside from providing the necessary evidence, answer questions related to values.

3. Research Method for Community-Based Risk Communication

The pilot program was conducted to develop and experimentally validate a methodology of community-based risk communication. As shown in **Figure 2**, a platform-style research forum was organized to allow the involvement of researchers in the fields of radiobiology, sociopsychology, risk communication, public participation, and social responsibility as well as their collaborators and local community members. A steering committee was established to conduct the pilot program.

The steering committee engaged in wide-ranging discussions to consider a method of validating community-based risk communication by analyzing issues such as the following: the memberships and methodologies of the study groups on community-based risk communication; the involvement of experts; the adequacy of the process for its practical application; and the methods for evaluating the group's achievements.

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[i] "The right to make autonomous decisions about one's life and lifestyle free of any pressure from the authority or society" (translation of the definition provided in the Japanese dictionary *Daijirin*)

[ii] Recognition of the possibility of becoming successful or achieving a goal under certain circumstances through one's own ability.

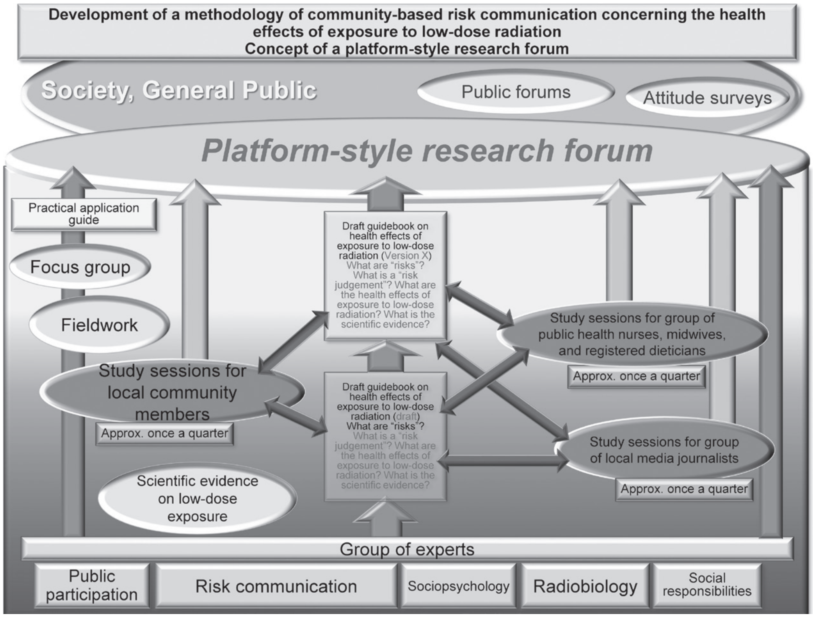

Figure 2 Concept of the platform-style research forum

III. Community-Based Risk Communication in Practice

1. Drafting a Guidebook for Solving Problems

As the first step in addressing impediments to public recognition of the risks associated with low-dose radiation and related challenges, mainly researchers led the drafting process for a guidebook on the health effects of low-dose radiation. This draft was discussed in a platform-style research forum to explore the desired risk communication collaboratively in accordance with local characteristics.

The draft took into account the following three factors.

- Scientific evidence on the health effects of low-dose radiation
- How uncertainties that cannot be validated exclusively by scientific means should be handled
- Psychosocial effects

Space limitations prevent us from going into detail, but the draft has a total of 46 pages and is structured as follows.

- Introduction
- Concept of risks
- Somatic effects of radiation
- What is a low dose?
- Health effects of low-dose radiation
- Conclusion
- Supplement and reference

The draft not only discussed the health effects of radiation in a scientifically sound manner, but also clarified the psychological effects of radiophobia as well as the risks and methods required to make the necessary judgements.

2. Study Sessions with the Local Community

A pilot program was conducted with study groups while using the draft guidebook on the health effects of exposure to low-dose radiation as a learning material.

(1) Study sessions conducted with the draft guidebook

The following three study groups were established to carry out a series of study sessions using the draft textbook.

(A) Group of women who live in Tsuruga (12 persons)
(A group of women interested in nuclear)
(B) Group of professionals from the health care center in Tsuruga (12 persons)
(Public health nurses, registered dieticians, midwives, and clinical psychotherapists)
(C) Group of media journalists (5 persons)
(Newspaper and network reporters from the Tsuruga press club)

Group C often failed to meet due to members having to cancel at the last minute. From fiscal 2014 onward, members of Group C began to join the meetings of Group A or B.

Lasting about two hours, each study session involved studying the draft to identify any points that were unclear, confusing, or incomprehensible and then rephrasing or modifying the text to make it clearer.

During the study sessions held in fiscal 2013, participants proposed the drafting of an introductory edition while taking into account inadequacies and improvement points that they had identified. In fiscal 2014, they began collaborating in the drafting of the introductory edition. The issues and necessary improvements that were identified are mentioned in a later section about revisions to the guidebook.

(2) Briefing exercises in groups

Exercises were conducted among Groups A and B to simulate briefings to local citizens and learn how best to communicate with them and provide explanations by using the introductory edition of the guidebook on the health effects of exposure to low-dose radiation, which had been jointly drafted with the members of the study groups. Graduate students from the University of Fukui played the roles of local citizens as the intended audience.

During the Q&A sessions held in the briefing exercises, participants exchanged opinions to clarify what they really understood and what they did not. At the same time, they clarified what matters would require particular attention and consideration when local citizens were invited to briefing sessions. These points were reflected in a guide for the practical implementation of the guidebook during actual briefings. **Figure 3** shows how study sessions and briefing exercises were conducted, while **Table 1** provides a record of the study sessions.

(3) Revisions to the guidebook

During study sessions conducted for the citizens of Tsuruga, the participants identified the following issues as requiring revision in the draft that had been prepared earlier by experts.

- Approach to risks: It is difficult to understand the definition, concept, trade-offs, probabilities, and uncertainties of risks.
- Somatic effects of radiation: Difficult terms are used, such as DNA damage and repair mechanisms, excessive absolute risks and excessive relative risks (EARs and ERRs), Sv, Bq, and Gy.
- What is a low dose?: The psychological consequences of the Chernobyl accident could be understood clearly.
- Health effects of low-dose radiation: It is difficult to understand the findings of

(a) A study session (Group A) (b) A briefing exercise (Group A)

(c) A study session (Group B) (b) A briefing exercise (Group B)

Figure 3 Views of study sessions and briefing exercises

Table 1 Record of study sessions

Study Group A	Study Group B	Study Group C
Jul. 12, 2013 16 persons	Nov. 12, 2013 13 persons	Jul. 31, 2013 7 persons
Nov. 8, 2013 12 persons	Jan. 17, 2014 16 persons	Nov. 11, 2013 3 persons
Jan. 17, 2014 10 persons	Mar. 17, 2014 16 persons	Jan. 23, 2014 1 person
Mar. 14, 2014 11 persons	Jun. 4, 2014 12 persons	Sep. 26, 2014 3 persons
May 16, 2014 10 persons	Jul. 30, 2014 12 persons	(These members later joined either Group A or B)
Jul. 11, 2014 12 persons	Sep. 24, 2014 10 persons	
Sep. 26, 2014 8 persons	Nov. 19, 2014 13 persons	
Nov. 7, 2014 12 persons	Mar. 12, 2015 13 persons	
Feb. 20, 2015 12 persons	Aug. 3, 2015 13 persons	
Aug. 21, 2015 8 persons	Oct. 7, 2015 20 persons	
Nov. 27, 2015 7 persons		

epidemiological studies on medical exposure, including the four models (LNT, etc.) and the computer tomography.

In general, these opinions can be roughly summarized as follows.

- Too much information makes it difficult to capture the overall picture.
- The structure and chapter breakdown should be modified.
- The content should be convincing for citizens and allow them to offer explanations to fellow citizens.
- Too many details are unnecessary for beginners. The introductory edition of the guidebook should be made shorter.

With these opinions in mind, revisions to the draft were begun in fiscal 2014. The introductory edition of the guidebook on the health effects of exposure to low-dose radiation was prepared after repeated revisions and modifications in collaboration with members of the study groups.

3. Preparation of a Practical Application Guide

During the study sessions and briefing exercises, it became quite clear that even a good guidebook cannot be fully understood simply by reading it or hearing a few explanations once or twice. A good guidebook can be made more effective if an appropriate method of putting it into practice is employed.

Given this, a guide was prepared to facilitate the practical application of the method used for community-based risk communication while taking into account the issues and challenges identified during the study sessions.

This guide facilitates the application of the guidebook on the health effects of exposure to low-dose radiation (introductory edition) in the practice of community-based risk communication in local communities. The guide was also summarized to produce a practical guide. The practical application guide and the practical guide have been made available on a website (www.cbriskcommunication.org), along with the guidebook on the health effects of exposure to low-dose radiation (introductory edition).

IV. Evaluation of Community-Based Risk Communication

Attitude surveys were conducted before and after the study sessions (November 2013 and November 2015) to examine how levels of understanding and attitudes among the participants had changed[7]. The questionnaire used for these surveys was similar to the one used in the attitude survey on radiation and risks conducted with the citizens of Tsuruga in September 2013. This similarity makes it possible for the attitudes of participants in the study sessions to be compared with those of other citizens in Tsuruga. The attributes of these participants can also be understood through factor analysis.

In the analysis of attitudes among the citizens of Tsuruga[6], the responses were classified into five groups, with three groups representing moderate opinions set between the most concerned group and the most accepting group at the two extremes. The 24 members of the study groups were mainly classified into the most concerned group together with the first and the third groups in the middle. Only three of the members were classified into the most accepting group. Thus, these participants represented a typical mixture of intermediate groups and the most concerned group.

In total, 44 questions were asked. Due to space limitations, **Figure 4** presents only some of the changes in attitudes among participants in the study sessions. The lightly shaded bars represent responses before the study sessions, while the heavily shaded bars represent responses after the study sessions. For comparison, the results of the earlier attitude survey conducted with the citizens of Tsuruga are also represented using solid lines.

After the study sessions, fewer people had negative views or fear toward radiation, and a larger number of people had a more positive attitude that radiation itself is neither good nor bad.

Figure 5 shows how perceptions of food from Fukushima and risks changed before and after the study sessions. While 20% of the citizens of Tsuruga avoided food from Fukushima, the participants developed a notably stronger tendency to deny such an aversion after the study sessions. After the study sessions, the respondents had a better understanding of the methods used to determine risks.

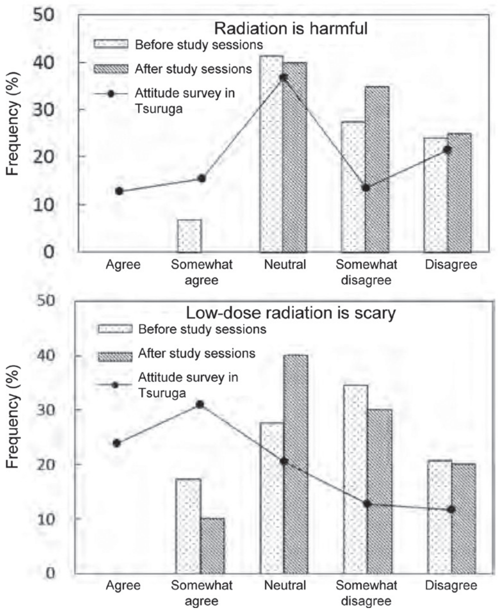

Figure 4 Changes in attitudes among participants in the study sessions

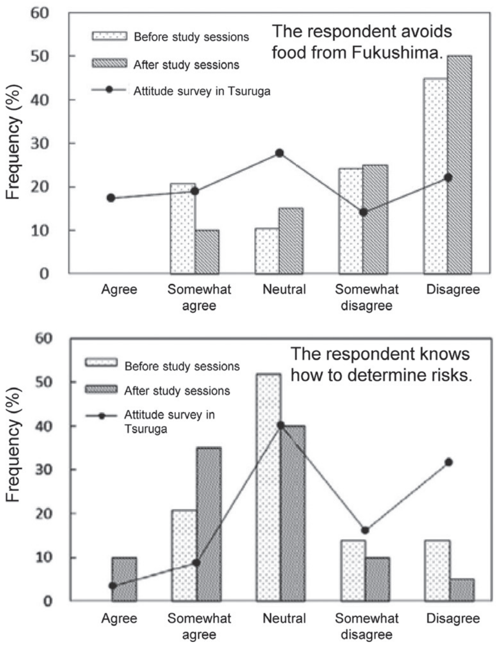

Figure 5 Changes in perceptions of food and risks among participants of study sessions

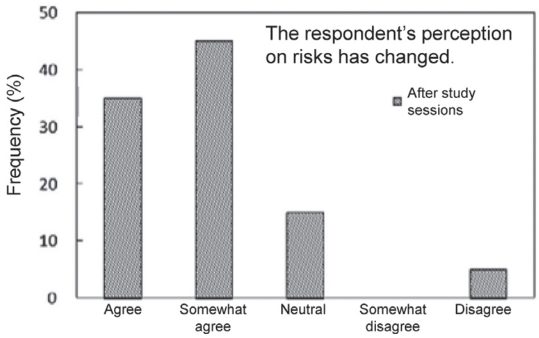

Figure 6 Changes in the perception of risks among participants in the study sessions

Furthermore, after the study sessions, many participants responded that these sessions had changed their attitudes (**Figure 6**).

In this manner, the pilot program verified that the study sessions had changed attitudes towards radiation health risks and validated the method adopted for community-based risk communication.

V. Perspectives for Community-Based Risk Communication

In March 2016, a public forum was held in Ookayama, Tokyo, to discuss the health effects of low-dose radiation. Opinions were exchanged among a total of 40 and some participants, including citizens interested in risk communication related to these health effects, practitioners of risk communication, and researchers in related fields.

Details concerning what was discussed at the public forum are saved for another time, but community-based risk communication is clearly a more useful method for allowing communities to discuss and address local challenges together.

The fact that there were only a few participants is often misinterpreted as reflecting a narrow scope of application. In fact, many insights can be obtained effectively by applying this method in many other communities.

Some people feel that this method is less effective and efficient than conventional large-scale briefing sessions and town meetings. However, it is highly doubtful that honest opinions and views can be heard at briefing sessions attended by a large number of participants.

Community-based risk communication can be scaled up to a global level by first having local community members visualize how global challenges affect their communities. After that, the targets can be expanded across multiple regions and many communities.

The pilot program demonstrated that the success or failure of risk communication depends on the quality of the guidebook and the method used to apply it in practice. The author hopes that local communities throughout Japan will lead the way in community-based risk communication to validate its effectiveness in resolving various challenges. The pilot program was financed by a JSPS Grant-in-Aid for Scientific Research (No. 25420902).

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