## Chapter 2 :Characteristics and Significance of Decontamination

### 2.1. Characteristics of Radioactive Contamination and Decontamination

#### 2.1.1. Characteristics of Radioactive Contamination

##### (1) Dispersion of Radioactive Materials

As a result of analysis by the Nuclear Safety Authority, the total amounts of radioactive substances released from the TEPCO Fukushima Daiichi NPS were estimated at about $1.1 \times 10^{19}$ Bq for xenon 133, $1.6 \times 10^{17}$ Bq for iodine 131, $1.8 \times 10^{16}$ Bq for cesium 134, $1.5 \times 10^{16}$ Bq for cesium 137, $1.4 \times 10^{14}$ Bq for strontium 90, $1.9 \times 10^{10}$ Bq for plutonium 238, $3.2 \times 10^{9}$ Bq for plutonium 239 and $3.2 \times 10^{9}$ Bq for plutonium 240 [26,27], a large amount of radioactive materials was dispersed into the atmosphere. The dispersed radioactive materials descended to the ground with rainfall, etc., and contamination was observed in a wide area, mainly in Fukushima Prefecture.

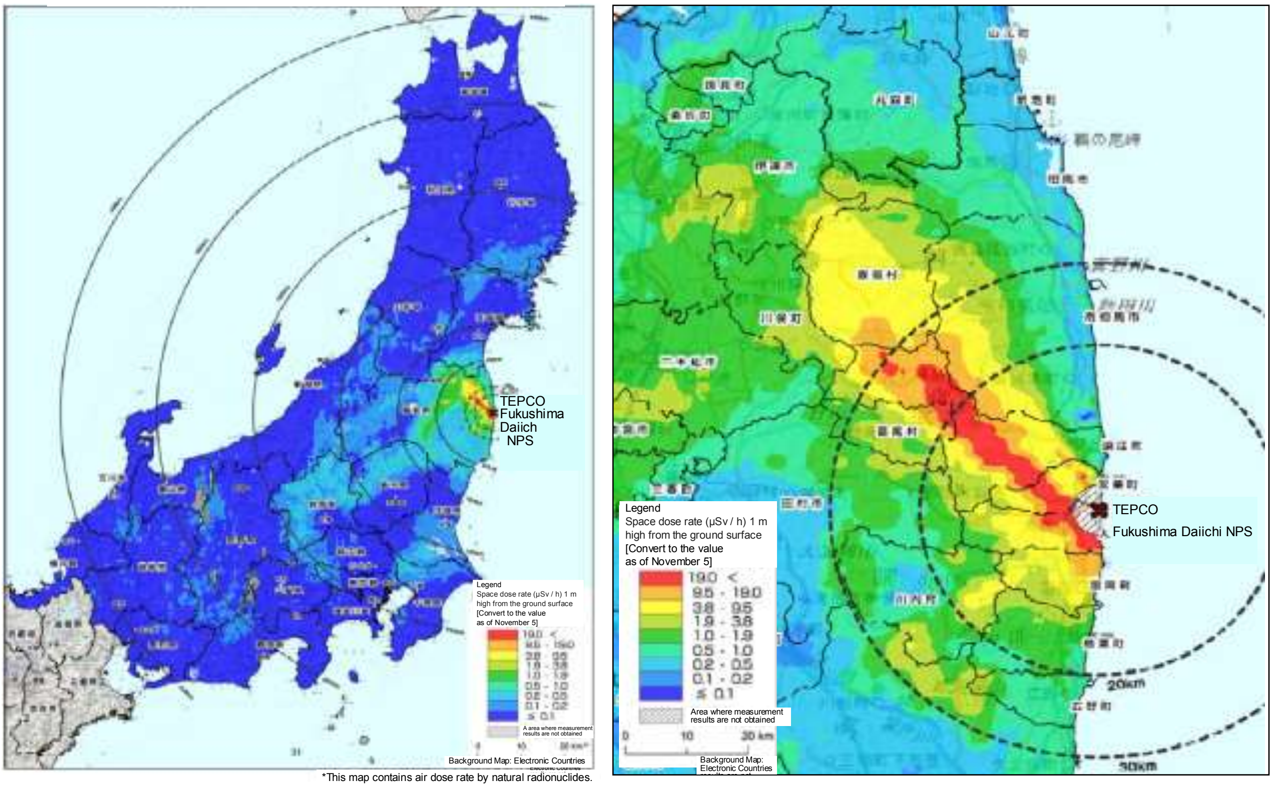


**Figure 2-1 Results of 4th aircraft monitoring by MEXT** (October – November, 2011)

Source: Measurement results of 4th aircraft monitoring by MEXT (December 16, 2011)

##### (2) Contamination by Radioactive Cesium

Radioactive substances released included cesium 134, 137 and iodine 131, as well as xenon 133, tellurium 129, strontium 89, 90 and plutonium 238, 239, and 240. In subsequent soil surveys, cesium 134, 137,

26 NERHQ, "Report of the Japanese Government on the IEAEA Ministerial Conference on Nuclear Safety" (June 2011)

27 MOE, NIRS, "Unified basic data on health effects etc. by radiation FY2016 edition"

iodine 131, tellurium 129, silver 110, strontium 90, plutonium 238, 239, 240 were observed. [28]
Soil surveys conducted by MEXT in June 2011 and January 2012 found plutonium 238, 239, and 240 within the range of atmospheric nuclear test impacts observed nationwide before the accident from 1999 to 2009, except in one location where plutonium 238 deposition was detected (at about 1.4 times the maximum value of plutonium observed before the accident). The strontium 90 was also within the range of the impacts of past atmospheric nuclear tests. [28] The 50-year cumulative execution dose of plutonium and radioactive strontium are very small compared to cesium 134 and 137 at each place where the highest deposition amounts were detected. [29]

Furthermore, since the half-life is as short as about 8 days for iodine 131, about 5 days for xenon 133, and about 3 days for tellurium 132, there is little medium- to long-term radiation exposure impact, and at the time of the establishment of the Act on Special Measures (August 26, 2011), the abundance ratio of iodine 131, for example, was 0.0001% or less than the ratio immediately after the accident, and it was not detected.

Based on these facts, two nuclides deposited were important for considering human exposure caused by the TEPCO Fukushima Daiichi NPS accident. These were cesium 134 (half-life of about 2.1 years) and cesium 137 (half-life of about 30.2 years).

### (3) The Scale of the Accident and the Social Background

In the International Nuclear and Radiation Event Scale (INES) evaluation, which is an international indicator of the magnitude of accidents and trouble at nuclear power stations, etc., the TEPCO Fukushima Daiichi NPS accident is at the Level 7 (serious accident), the same as the Chernobyl nuclear accident. When comparing the amount of radioactive materials released to the atmosphere, the TEPCO Fukushima Daiichi NPS accident is estimated to be about 10% of the Chernobyl nuclear accident. In other major accidents, the Three Mile Island nuclear accident was Level 5 (accident with wider consequences), Tokaimura JCO criticality accident was Level 4 (accident with local consequences). [28]

In accidents that occurred in the former Soviet Union, such as the Chernobyl nuclear accident and the South Ural nuclear facility accident, the information disclosure and the response of the government, was not done sufficiently due to information regulations. Also, they occurred in a country with a vast land area called the former Soviet Union, and accident responses were based on resettlement. Meanwhile, the TEPCO Fukushima Daiichi NPS accident occurred in Japan, a country with a more limited land area occupied by many inhabitants, and there was an expectation that the accident response would involve having them return to live. In addition, government announcements and media reports disclosed a lot of information right from the beginning of the accident, and much information also circulated via the internet, etc. Meanwhile, the response to radioactive contamination proceeded with a lack of adequate sharing of knowledge and information between experts and the public about the health effects and risks of radiation. [30]

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[28] MEXT, “On analysis results of MEXT, (1) analysis results of gamma ray emitting nuclides, and (2) analysis results of strontium 89, 90 (secondary distribution survey)” (September 12, 2012)
[29] MEXT, “On the results of nuclide analysis of plutonium and strontium by MEXT” (September 30, 2011)
[30] Prime Minister's Official Website "Enhancement of science education on health risk of radiation - Japan Science Council Recommendation - " (http://www.kantei.go.jp/saigai/senmonka_g72.html)

**Table 2-1 Comparison of Estimated Emission of Representative Radionuclides of Chernobyl and TEPCO Fukushima Daiichi NPS**

| Radionuclide | Half life | Amount released to the environment PBq ($10^{15}$ Bq) | | TEPCO Fukushima Daiichi NPS/ Chernobyl |
|---|---|---|---|---|
| | | Chernobyl | TEPCO Fukushima Daiichi NPS | |
| Xenon (Xe) 133 | About 5 days | 6500 | 11000 | 1.69 |
| Iodine (I) 131 | About 8 days | ～1760 | 160 | 0.09 |
| Cesium (Cs) 134 | About 2 years | ～47 | 18 | 0.38 |
| Cesium (Cs) 137 | About 30 years | ～85 | 15 | 0.18 |
| Strontium (Sr) 90 | About 29 years | ～10 | 0.14 | 0.01 |
| Plutonium (Pu) 238 | About 88 | $1.5\times10^{-2}$ | $1.9\times10^{-5}$ | 0.0012 |
| Plutonium (Pu) 239 | About 24,100 years | $1.3\times10^{-2}$ | $3.2\times10^{-6}$ | 0.00024 |
| Plutonium (Pu) 240 | About 6,540 years | $1.8\times10^{-2}$ | $3.2\times10^{-6}$ | 0.00018 |

Source: Ministry of the Environment and Radiological Medicine Research Institute "Unified basic data on health effects, etc., from radiation. Fiscal year 2016 edition."

### (4) Background and Characteristics of Japan and Fukushima Prefecture

In Japan, about 66% of the country is occupied by forests, about 12% by agricultural land and about 5% by residential areas, and population density of inhabitable areas tends to be high.[31] Fukushima Prefecture received the strongest impacts of the TEPCO Fukushima Daiichi NPS accident; the total population before the earthquake was about 2 million people, and the total area is large at about 14,000 km$^2$, with forests at about 71%, farmland at about 11%, water surfaces, rivers, waterways, etc., at about 3%, roads at about 4%, residential areas (including industrial sites, etc.) at about 4%, and other uses (parks, green spaces, resorts and recreation facilities, abandoned cultivation areas, etc.) at about 7%.[32] Also, because the eastern side faces the Pacific Ocean and the western side is surrounded by mountains, the situation is quite different in the east and west during the four seasons. There is a lot of snow in the Nakadori (middle) region, and in Fukushima City, the average number of snow days in the decade from 2005 to 2014 was 74 days a year; this region is characterized by having many snowfall days compared to the rest of the country. [33] (Figure 2-2)

Furthermore, it is an important point that the accident occurred at the facility for supplying electricity not for residents in Fukushima area, but for those in Tokyo metropolitan area.

[31] Fifth National Land Use Plan (National Plan) Overview
[32] Fukushima Prefecture, "Fukushima Prefecture Position Manual in FY2016" (https://www.pref.fukushima.lg.jp/sec/11045b/28youran.html)
[33] Meteorological Agency, "AMeDAS Fukushima Observatory, Onahama Observatory Observation Results for 10 Years of 2005-2014"

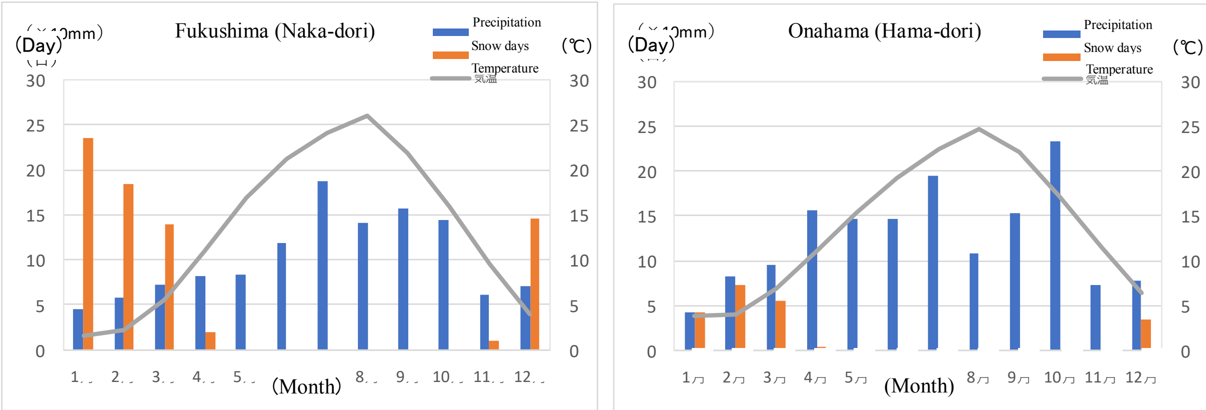



**Figure 2-2 Weather conditions in Fukushima Prefecture** (average over the past 10 years)

Source: Meteorological Agency AMeDAS at Fukushima Observatory and Onahama Observatory Observation Results for 10 Years, 2005 to 2014

Fukushima Prefecture borders on six prefectures of the Tohoku (northeastern) region (including Niigata prefecture) and metropolitan area, has the third-largest area in Japan after Hokkaido and Iwate Prefecture, and is divided into three zones ("Hamadori," "Nakadori" and "Aizu"). Seven habitable areas are formed on the nodules of six connected axes, with three in the vertical north-south direction and three in the horizontal east-west direction, making this a multi-polar, decentralized prefectural structure with cities dispersed on each axis.

It is located in near to the Tokyo metropolitan region, about 200 km from Tokyo, making it a point of contact between the Tohoku and the metropolitan regions. It has advantageous geographical conditions for becoming a base for exchanges of people and goods, for locating businesses and expansion of a mobile population, via the Tohoku Expressway, Joban Expressway, and Tohoku-Yamagata Shinkansen connecting the Tohoku area and the Tokyo metropolitan area, as well as the BanEtsu Expressway connecting the Pacific side and the Japan Sea side of the country, plus Fukushima Airport, Onahama Port, Soma Port and other infrastructure.

Before the disaster, this prefecture was the top power producer in Japan, supplying about one-third of the electricity consumed in the metropolis and three prefectures in the metropolitan region centering on Tokyo. In FY2010, manufactured goods shipments amounted to about 5.1 trillion yen (ranking 20th nationwide and 1st in the Tohoku area including Niigata Prefecture), agricultural output was valued at about 233 billion yen (ranking 11th nationwide), and Fukushima was in the top class for agricultural products capacity nationwide.

It is blessed with the natural environment, and with attractions such as Lake Inawashiro, Mount Bandai and the Oze Marshland, is well-suited as a place for green tourism and people with two homes, and has abundant tourism and recreational facilities such as hot springs, golf course and ski resorts. In addition, it is a place colored by history and tradition, with many cultural assets such as Tsuruga Castle and the

Shiramizu Amidado Buddhist chapel. [34]

### 2.1.2. Characteristics of Decontamination after the TEPCO Fukushima Daiichi Nuclear Power Station Accident

The decontamination projects associated with the TEPCO Fukushima Daiichi NPS accident are influenced by the contamination conditions, geographical factors, and the approach to deal with residents, etc., and have the following characteristics.

#### (1) Decontamination of Contamination from Radioactive Cesium

As mentioned above, pollution caused by the TEPCO Fukushima Daiichi NPS accident is mainly caused by radioactive cesium. Radioactive cesium released into the atmosphere by the accident descends to the ground with rain, etc., adheres to buildings, soil and plants, etc., and accumulates in rainfall tracks, gutters, puddles, and depressions, etc. In the environment, cesium is generally more likely to adsorb to soil that contains clay minerals than to be dissolved in water, and it adsorbs near the surface layer of the soil, such as in household gardens or farmland.

Also, the locations of radioactive cesium became patchy with the passage of time after the accident, resulting in some “hotspots” having high doses, due to the fact that radioactive cesium migrates with soil and other adsorbent materials, influenced by rain and other factors over time, and the tendency to accumulate depends on the shape and material of the affected structure.

Decontamination work, such as the cleaning of buildings and removal of topsoil, was implemented based on these characteristics of radioactive cesium and the characteristics of contamination that varied depending on the target of decontamination.

In general, it is most effective to implement decontamination starting with locations that have high doses, in order to prevent the spread of contamination by fallout of radioactive substances that have descended to the ground. However, since cesium tends not to spread much after it has settled in soil, etc., decontamination work was implemented with a priority on inhabited areas in order to restore living conditions.

#### (2) Implementation of Decontamination Work with a Priority on Restoring Living Conditions

Under the IAEA’s international rules on measures for decontamination and other environmental remediation, organizations responsible for contamination countermeasures are expected to formulate implementation plans and implement decontamination, and regulatory bodies are to approve the plans. These international rules were not in mind at the time of the establishment of the Act on Special Measures, but as the TEPCO Fukushima Daiichi NPS accident resulted in extensive contamination and would require large-scale decontamination work, rapid responses would be difficult if it was the polluter implementing the decontamination. As a result, it was considered to be appropriate to have a framework in which the national and local governments would be implementing decontamination projects, while also ensuring that

[34] Fukushima Prefecture, "Regarding Fukushima's Present Condition and Efforts toward Reconstruction" (5th Symposium of Decontamination and Waste Technology Council, November 16, 2016)

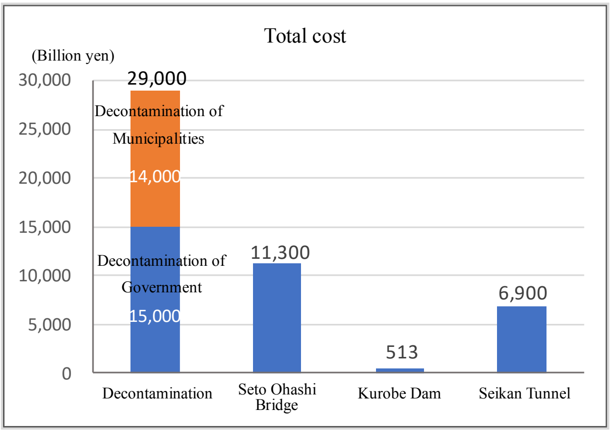
the polluter bears unambiguous responsibility.

Also, one issue in the extensive evacuation area was the prompt return of evacuees, who peaked at about 165,000 people, as well as quickly promoting safety and security measures, so decontamination activities were given the priority, whereas reconstruction plans were not considered. At this time, considering the indication that life under evacuation should be limited to three years, it was assumed that their return should occur within three years of the disaster, so original policies stated the goal of completing decontamination work in Areas under Evacuation Orders within just over two years, by FY2013.

### (3) Large-scale, Extensive Decontamination Work in Extensive Areas Affected by the Earthquake and Tsunami

Because of the extensive area contaminated by radioactive substances, the area targeted for decontamination was extremely large, and according to the Act on Special Measures, the SDA where the Ministry of the Environment (MOE) was to implement decontamination contained 11 municipalities (population about 80,000 people, area about 1,150 $km^2$), and the Intensive Contamination Survey Areas (ICSA) where municipalities and others were to implement decontamination contained 104 municipalities (population about 6.9 million people, area about 24,000 $km^2$), which included four municipalities in the SDA. These areas contained many populated areas such as urban areas as well as agricultural lands.

The decontamination projects were unprecedented in the history of public works in Japan and in the world due to the extensive area involved in large-scale work being done simultaneously in multiple municipalities over a short period of time. In the SDA alone, a cumulative total of 13.6 million workers were involved over a period of four years and seven months to the end of January, 2017. The scale of the effort is evident from the number of workers involved over a short period of time compared with other major civil engineering projects in Japan. (Figure 2-3)



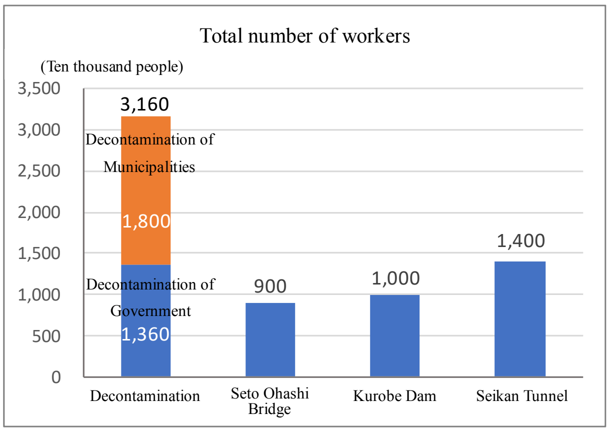




**Figure 2-3 Decontamination and other major projects in Japan**

Note: The total cost of decontamination work is as of September 2017, and the total costs of other civil engineering works are as of the time of each project.

The numbers of workers for decontamination work under the Ministry of the Environment are as of the end of January 2018, and the numbers of workers for decontamination work by municipalities are as of the end of November 2017.

Construction period of each project

Decontamination: July 2012 - March 2017 (4 years and 9 months)

Seto Ohashi Bridge: October 1978 - April 1988 (9 years 6 months)
Kurobe Dam: April 1956 - June 1963 (7 years 2 months)
Seikan Tunnel: May 1964 - November 1987 (23 years 7 months)

Source: Bridge and Offshore Engineering Association “Document of Seto Ohashi Bridge Construction” (October 1988), Kansai Electric Power Company “Kurobegawa Fourth Power Station Construction History” (September 1965), Hokkaido Railway Company “Seikan Tunnel in Numbers”

In addition, the area targeted for decontamination is also characterized by having many places that suffered damage from the earthquake and tsunami. Particularly in places with significant damage caused by the earthquake or tsunami, it was a challenge to balance the remediation work with the disposal of residue and decontamination where housing and infrastructure were damaged. Notably, it was necessary to consider decontamination work without the benefit of a clear recovery policy in coastal areas that had ground subsidence, saltwater intrusion, and tsunami deposits, and extensive areas where housing had been lost. The circumstances differed depending on whether or not it was an evacuation area.

In SDA which were also Areas under Evacuation Orders, residents had evacuated and business activities were also restricted. As a result, the restoration work of infrastructure, etc., tended to be delayed, but it was still necessary to proceed with the decontamination work. Actions such as obtaining consent from stakeholders and explaining decontamination results were to be carried out with cooperation of municipalities at various places where evacuees were located. Since this region, particularly mountainous areas, did not have well-developed transportation networks and access and accommodation were restricted, it was necessary to devise the means to transport large numbers of decontamination workers and equipment to the area, and to secure workers to do the decontamination. Furthermore, because living and farming were now impossible, houses and roads deteriorated with the passage of time, and agricultural land converted to grasslands and became overgrown with bushes, which hindered subsequent decontamination activities.

Meanwhile, in ICSA outside of evacuation areas, decontamination activities were carried out even while people went about their daily lives and farming.

### (4) Responses to the First Decontamination Projects

Environmental pollution from a nuclear power station accident had not been expected to occur in Japan, so the legislative system and framework for responses were not sufficiently developed. For this reason, it was an urgent task to develop the legislation and a practical framework of procedures for emergency responses.

Also, as it was necessary to proceed in a situation of insufficient technical knowledge and systems, decontamination work was carried out in stages using the technical knowledge as available from Decontamination Model Projects, etc.; first, small-scale “preliminary decontamination” work was done on facilities that could be used as a base for decontamination, restoration and reconstruction work (municipal offices and public facilities, etc.); after that, work progressed on to large, full-scale decontamination.

In addition, as MOE was to conduct decontamination work based on the “Basic Policy for the Act on Special Measures concerning the Handling of Environment Pollution by Radioactive Materials ,” MOE developed common specifications and standards for cost estimation necessary for decontamination work and gradually improved them through trial and error in response to the actual situation at the decontamination sites. In that effort, MOE made use of the existing rules and mechanisms established by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and the Ministry of Agriculture, Forestry and Fisheries (MAFF), with the assistance of the MLIT and the MAFF, etc., which have abundant experience in public works projects.

Also, similar to large-scale construction projects, the mobilization of a large number of workers and appropriate command and management are also required under certain radiation environments. Therefore, large general construction contractors with expertise in large-scale construction and know-how of construction management such as worker management were used for decontamination works. In decontamination works by municipalities, depending on the situation, general construction contractors were used in some cases and local construction companies or other contractors were used in other cases.

### (5) Decontamination Aimed at First-stage Rebuilding of Residents' Lives

Due to the urgency of securing safety as quickly as possible, as well as recovery and reconstruction, there was no choice but to begin the decontamination work without sufficient time to prepare adequate policies. Therefore, as mentioned above, the PDCA (Plan-Do-Check-Act) cycle was emphasized, and information that was not available or grasped at the preparatory stage was incorporated over time make up for time constraints that existed at the preparation stage.

Also, it was decided that the scope of decontamination work would include living areas such as residential areas, schools, parks, large facilities, roads and farmlands, and the forests around residential areas, and decontamination work then advanced from the perspective of reducing impacts on the living environment.

To carry out decontamination smoothly, it would be preferable to secure disposal sites for removed materials in advance of decontamination work. However, as it is difficult to secure large-scale disposal sites quickly in advance, decontamination is proceeding by securing a large number of small-scale temporary storage spaces, referred to as Temporary Storage Sites. It is difficult to secure temporary storage space in municipalities with ICSA where residents live and farmland is being used. For that reason, after obtaining consent from the relevant persons, work was also carried out using "on-site storage" and other means with temporary storage in yards in decontaminated residential areas, with the aim of completing decontamination as soon as possible.

### (6) Considering the Preservation of Communities and Protection of Rights

In order to enable residents to return to their original lives as soon as possible, it would not be enough to simply proceed with decontamination, but rather, to proceed with consideration of their subsequent living so as not to destroy local communities. For this reason, it was decided to proceed with decontamination focused on community units, such as a neighborhoods or administrative districts.

This was because, besides the fact that decontamination would not be effective unless it was done area wide, community unit such as neighborhoods and administrative districts are important units for local decision making and programs in Japan. The same is true when establishing temporary storage sites and evacuation areas, so consideration was given to these units of division.

In the ICSA, attempts were made to minimize scraping and wiping so as to avoid destruction of residents' property, etc. Also, for agricultural and other lands, if farmers requested, attempts were made to choose decontamination methods that would avoid removing the soil surface, so as to maintain the functions of agricultural soil.

In carrying out decontamination, based on the Act on Special Measures, to the extent possible, decontamination was done after obtaining consent from residents. It was decided not to forcibly conduct decontamination against residents' wishes, and rather, in collaboration with residents to comprehensively judge the situation based on the extent of contamination and the importance from the residents' perspective, and decide whether or not to conduct decontamination, as well as details of decontamination methods, etc. Decontamination implementation plans were shared and agreed with residents.

| **Column** | "Case Study on Overseas Environmental Restoration Work and Lessons"<br>Mr. Tadashi Inoue, member of committee |
|---|---|

There are several cases of overseas environmental pollution caused by radioactive substances, as happened centering in Fukushima this time. They are largely divided into pollution of the living environment of the general public caused by the accident, and contamination of soil and groundwater in nuclear facilities (facilities used for manufacturing nuclear materials, etc.). As for significant environmental pollution caused by an accident, in 1957, at the MAYAK (former secret facility) nuclear power complex north of the city of Chelyabinsk in the former Soviet Union, there was a failure of the cooling system for storage tanks of high-level radioactive liquid waste generated from the reprocessing of spent fuel. As a result, the liquid waste dried up, the temperature rose, and some components of the dried waste caused a chemical explosion. As a result, contamination of $3.7 \times 10^9$ Bq/km$^2$ or more spread over a width of 30 to 50 km and a length of 300 km. The tank that exploded had contained various radioactive substances, but strontium-90 had the greatest effect on environmental pollution, and decontamination was done for soils, roads, vehicles, etc. There were more than 200 population settlements in this contaminated area, more than 1,300 people were evacuated from four villages immediately after the accident, and later, about 1,200 people moved from 24 villages. I visited this area in 1992, but even then I was required to wear a white coat and protective shoes. (Currently entry into this area is severely restricted). I have heard that there are still areas where entry is prohibited.

The next major environmental pollution case was due to an accident at the Chernobyl nuclear power station in the former Soviet Union (currently Ukraine). However, since many reports (see note) have been published about this, I will only briefly describe it here.

In April 1986, the core of Chernobyl Nuclear Power Station Reactor No. 4 exploded and radioactive materials was dispersed broadly into the environment. The major difference of environmental pollution between the Chernobyl accident and the TEPCO Fukushima Daiichi NPS accident is that in the former case the burning continued for 10 days in the reactor, so that the radioactive materials scattered included not only radioactive iodine, cesium, and strontium, but also such as plutonium and other constituents of nuclear fuel. (In the latter case was a core melt, so the main materials scattered included volatile iodine and cesium.) Also, the contaminated area in the case of Chernobyl was much greater than in Japan, affecting not only the former Soviet Union but also more distant countries such as Finland and Sweden on the Scandinavian peninsula, as well as Austria. Although decontamination of soils, buildings, roads, water sources, etc., was carried out there from 1986 to 1989, even today entry is prohibited into areas with high concentration contamination, and in the 30 km no-entry zone, pollution by transuranic elements (plutonium, americium, etc.) will makes agricultural production impossible for the next 1,000 years. Although decontamination was carried out in the above two examples, the current situation is that in Chernobyl it was not done as precisely as in Japan, because of the large scale of the country and the low population concentration.

Based on this experience in Chernobyl, international organizations have played a central role in creating international standards for environmental remediation after an accident. The International Commission on Radiological Protection (ICRP) has established the fundamental principles of radiological protection after an accident (ICRP Pub. 103 (2007) Fundamental Recommendations), the Application of the Commission's Recommendations for the Protection of People in Emergency Exposure Situations (ICRP Pub. 109 (2009) Emergency Situations) and the Protection of People Living in Long-term Contaminated Areas after a Nuclear Accident or a Radiation Emergency (ICRP Pub. 111 (2009) Post-Accident Recovery). In addition, the International Atomic Energy Agency (IAEA) has issued reports on exposure dose standards for environmental remediation (e.g., IAEA Safety Guides) and environmental remediation strategies, etc. These are undergoing revisions currently based on the Fukushima accident. In addition, the European Commission led the EURONOS project in preparation for the case of an accident like Chernobyl in the future, and prepared four kinds of guidebooks, including "Residential area management handbook in Europe," "Drinking water management handbook," and "Food production management handbook." Meanwhile, the UK has been operating the Windscale Nuclear Power Complex for many years, and Public Health England published the "Environmental Recovery Handbook" (2009). Also, in June 2015, the "UK Recovery Handbooks" for radiation and chemical incidents were published.

Next, I will introduce two very particular examples. In September 1987, a Cs-137 capsule that was left in an abandoned hospital in Goiania, Brazil, was stolen. Due to rumors that there were useful metals in it, the capsule was opened, Cs-137 spread around the city, and 1 $km^2$ was contaminated. This incident caused great concern for local residents. In order to restore this area, pollution was removed by evacuation of about 200 residents, dismantling houses, covering soil with concrete, and removing the surface soil. Another case was that in 1966, a US military aircraft carrying four nuclear bombs crashed in the air above Spain, plutonium from two bombs was released, causing environmental pollution in the Palomares region. Four sites and a total of approximately 50,000 $m^3$ of soil were contaminated. As soil was removed, sieving was carried out as soil decontamination. Again, the concern of the residents was great, and environmental remediation work and dialogue with the residents were carried out to dispel them.

Finally, in the UK, France, and the US, some nuclear power complexes have been in use since the 1950s, and some soil contamination countermeasures have been done. For example, soil and groundwater have been contaminated at the Hanford facility in the United States, and the world's largest cleanup program has been in progress there since 1989 with target completion in 2050. (The entire facility has an area of about 2.4 times that of Tokyo's 23 wards, and access and inhabitation by the general population are prohibited.)

In all of these cases, as well as experience in Fukushima, the utmost effort was needed for local understanding, and it has been pointed out that it is important to explain the accident and have the involvement of stakeholders (residents, local representatives, business operators, regulatory bureaus, government, etc.) in environmental remediation. For any repair, this has been raised to be a top priority, and without it we cannot effectively restore the environment. A woman who was in charge of dialogue with residents at the Savannah River facility in the United States made an impression when she told me that the US has long experience in communicating with the community, but Japan is still relatively at the entry level, so there is a need to learn from the example of Fukushima in the future.

As mentioned above, standards and guidebooks on environmental remediation have been created so far due to accidents. However, in many countries, when such an accident happens, in many cases strategies have not yet been established how to evacuate the residents, establish restricted areas, and restore the environment, etc. Therefore, it is necessary to create the legislation in advance and prepare frameworks that ensure the safety of residents and restore the environment as quickly as possible right after an accident.

Note: One example is “Environmental Consequences of the Chernobyl Accident and their Remediation: Twenty Years of Experience,” Radiological Assessment Reports Series, IAEA 2006.

## 2.2. The Significance and Objectives of Decontamination

### 2.2.1. The Significance and Necessity of Decontamination

#### (1) What is Decontamination?

The decontamination work associated with the TEPCO Fukushima Daiichi NPS accident was the removal of radioactive materials, and shielding, etc., in order to reduce the radiation dose in living areas, based on the following three methods. [35]

① Remove (removal)

Remove radioactive materials from living areas by scraping the top soil, removing branches and leaves, washing the building surface, etc., where radioactive materials were attached.

② Block (shield)

Covering the radioactive materials with soil, concrete, etc., can shield the radiation, making it possible to lower air doses and radiation doses.

③ Keep away

The intensity of radiation weakens as one moves away from the radioactive material. Therefore, if you move the radioactive substance away from people, you can lower the exposure dose to humans. Also, shortening the time spent near radioactive materials will function as "keeping away."

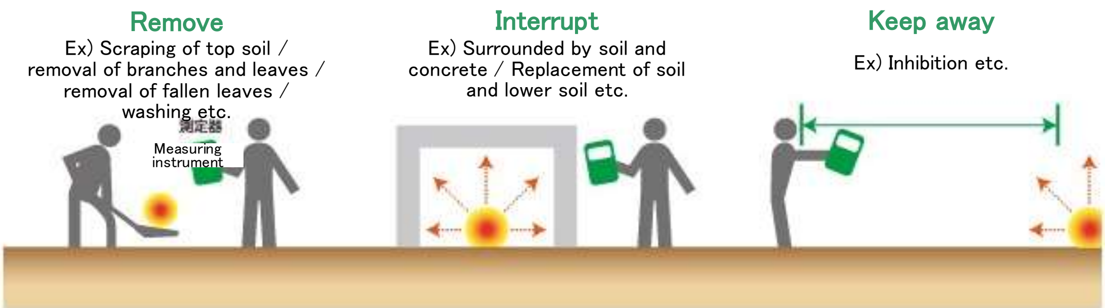



**Figure 2-4 Methods for reducing exposure doses due to radioactive substances in the environment**

#### (2) The Necessity of Decontamination

Since radioactive substances decrease with time (physical attenuation) and the decay effect due to natural factors such as wind and rain (weathering), the radiation dose decreases even if decontamination work is not done, but it takes a long time to reduce. For this reason decontamination is necessary in order to reduce radiation doses of residents living in contaminated areas, enable the early return of evacuees and restoration of livelihoods.

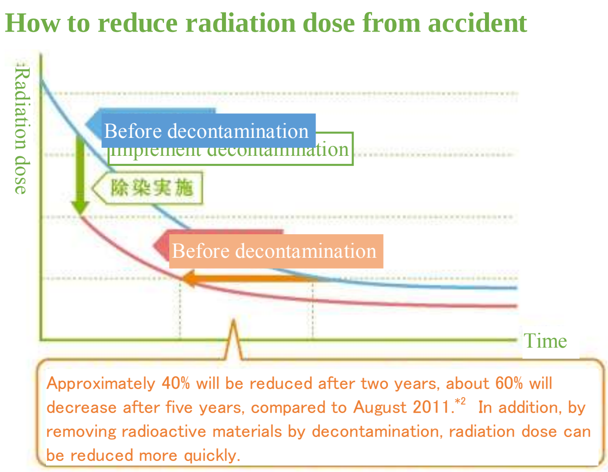



**Figure 2-5 Natural decay of radiation**

35 MOE, "The Decontamination Information Site" (http://josen.env.go.jp/about/method_necessity/index.html)

### 2.2.2. Concepts of Radiation Protection and the Objectives of Decontamination

#### (1) ICRP Recommendations and Standards for Radiation Protection

ICRP is an international organization composed of scientists and experts from around the world who are knowledgeable about radiation protection measures and its recommendations are widely accepted as an international standard for radiation protection. Governments in each country implement specific protective measures based on the basic concepts presented in ICRP recommendations, IAEA guidelines for radiation protection, and so on.

According to the ICRP's 2007 recommendations (ICRP Publication 103), [36] if the source of exposure due to an accident or other cause cannot be controlled, as an "emergency exposure situations ," an appropriate reference level is set according to the situation in the range of 20 to 100 mSv for annual or single exposure, and this is used as a measure for planning and implementation of protective measures. Thereafter, during recovery and remediation (referred to as an "existing exposure situations"), since the long-term goal is "to lower the exposure to a level that is close to the level considered to be normal, or an equivalent level," the reference level should be selected from the lower region in the range of 1 to 20 mSv/y.

#### (2) Standards for Evacuation Orders

In the initial protection measures of the TEPCO Fukushima Daiichi NPS accident, evacuation areas were determined by referring to the disaster prevention guidelines stipulated in "Emergency Preparedness for Nuclear Facilities" (Nuclear Safety Commission, June 30, 1980) . However, the disaster prevention guidelines are supposed to be evacuation in a short period of time and indoor evacuation, and there were no indicators for long-term protection measures in Japan. For this reason, 20 mSv/y which is the lower limit of the reference level range of 20 to 100 mSv/y that is supposed to be applied to emergency exposure situations under the ICRP recommendations, and corresponds to the most stringent value, was applied as a reference level for requiring evacuation. [37]

#### (3) Radiation Protection for the General Public

Regarding the use of schools, on April 19, 2011, MEXT announced a "Preliminary approach in deciding how to use school buildings and schoolyards in Fukushima Prefecture," in accordance with the upper limit of the reference level for existing exposure situations in the ICRP recommendations (1 to 20 mSv/y), and a policy was adopted setting the dose criterion for the use of schoolyards at the air dose rate of 3.8 μSv/h. (An exposure dose of 20 mSv/y corresponds to 3.8 μSv/h with an outdoor air dose rate assuming a pattern of spending 16 hours indoors (wooden building) and 8 hours of outdoor activities, and shielding factor of wooden houses of 0.4). Later, on August 26, 2011, "On the reduction of doses of school buildings and schoolyards in Fukushima Prefecture" was announced on a more safety-oriented basis, stating that the government aims for less than 1 mSv/y for the radiation dose that children and students in Fukushima

[36] The 2007 Recommendations of the International Commission on Radiological Protection ICRP Publication 103 (August 2009)

[37] NERHQ, "Standards for the review of the Areas under Evacuation Orders (Standard 20 mSv/y)" (July 2012)

Prefecture receive at school.

Regarding concepts of radiological protection of general residents, a statement “About the Basic Concept of Radiation Protection for Recovery and Release of Emergency Evacuation” released on July 19, 2011 by the Nuclear Safety Commission, stated that “We will select a lower dose of 1 to 20 mSv annually for range applied to existing exposure situations. An intermediate reference level can be set to gradually improve the situation, but in the long term, we aim for 1 mSv/y.”

### (4) Basic Guidelines of the Act on Special Measures

Even in areas where the estimated annual exposure dose (excluding medical exposure, same hereinafter) is less than 20 mSv/y, the “Basic Concepts for the Promotion of Decontamination” (August 26, 2011, Nuclear Emergency Response Headquarters) indicated aiming at effective decontamination with an estimated annual exposure dose approaching 1 mSv/y, with the cooperation of municipalities and residents. This principle was carried over to the basic guidelines based on the Act on Special Measures.

The basic guidelines based on the Act on Special Measures indicate targets for measures such as decontamination, and in areas where the annual additional exposure dose as of August 2011 was 20 mSv/y or more, the goal was to reduce the dose in stages and quickly. In areas with less than 20 mSv/y, the goal was 1 mSv/y or less per year in the long term.

The annual additional exposure dose of 1 mSv/y as this long-term goal was originally targeted for the additional exposure dose to humans, and it was not only for decontamination work, but also governmental objectives to be achieved including other protective measures. Nonetheless, regarding these basic guidelines, due to simple quotation of this numerical value, opinions were received that this target was perceived to be achieved only by decontamination.

### (5) Specific Criteria for Intensive Contamination Survey Areas (ICSA) and Decontamination Methods

In the “Basic Policy for Emergency Response on Decontamination Work” (August 26, 2011 Nuclear Emergency Response Headquarters) the long-term goal was that the additional exposure dose will be less than 1 mSv/y in areas of 20 mSv/y or less. Also, as the approach to decontamination, decontamination was considered necessary in areas with relatively high doses where doses were between 1 and 20 mSv/y, but in areas with relatively low doses, considering physical attenuation due to natural factors such as wind and rain (weathering effect), radioactive substances basically do not require surface decontamination, although decontamination of places that show high doses locally such as roadside drains and rain gutters (building eaves) was regarded as important.

Based on this, at the 2nd Investigative Committee on Remediation (September 27, 2011), the criterion for designation as an ICSA was set as areas where the exposure dose exceeds 1 mSv/y, and actually the air dose rate of 0.23μSv/h was set as the criterion for designation. This conversion method refers to the method used when converting 20 mSv/y to 3.8 μSv/h in the “Preliminary approach in deciding how to use school buildings and schoolyards in Fukushima Prefecture,” (April 19, 2011, MEXT Release No. Monka-Su-134).

Regarding the criterion for designation, on November 22, 2011, in “Radiation hazards based on the provisions of the Special Measures Law concerning the handling of pollution of the environment by radioactive substances released by nuclear power station accidents caused by the Tohoku Region Pacific Offshore Earthquake that occurred on March 11, Regarding the formulation of technical standards concerning prevention (consultation)," [38] the Minister of the Environment consulted the Chairman of the Radiation Council, and on December 13, 2011 the Chairman indicated that the decision was appropriate. [39] Based on this, on December 14, 2011, "Ministerial Ordinance that specifies requirements for designation of contaminated waste disposal areas" (Ministry of the Environment Ordinance No. 34, in 2011) was promulgated.

When considering the standards, numerical values were calculated on the safe side, as there had not yet been a sufficient accumulation of knowledge for converting radiation doses from air dose rates in the case of wide area contamination by radioactive substances. Opinions were voiced that for calculations on the safe side, the shielding effect should not be considered, while other opinions were voiced that more realistic coefficients should be used and therefore to include the shielding effect and staying time.

### (6) Concepts on Additional Exposure Doses

In specifying ICSA, it was thought that the additional exposure doses can be estimated by measuring the air dose rate if certain assumptions are made. For radiation protection in the TEPCO Fukushima Daiichi NPS accident, under certain assumptions, additional exposure doses of 1 mSv/y are assumed to be 0.23 μSv/h when converted to the air dose rate per hour. The concepts behind this assumption are as follows. [40]

・Unrelated to any accident, radiation already exists in nature, and the radiation dose from the Earth is 0.38 mSv/y (0.04 μSv/h). [41]

・Assuming a daily life pattern of a person who is in an area with a constant air dose rate both spatially and temporally, with the person staying outdoors for 8 hours and indoors for 16 hours (assuming a wooden house with a shielding coefficient of 0.4), the person's additional exposure dose will be 1 mSv/y, which corresponds to 0.19 μSv/h for the air dose rate.

※ 0.19 μSv/h × (8 hours + 0.4 × 16 hours) × 365 days = 1 mSv/y

・In measurements of the air dose rate using NaI scintillation type survey meter , the radiation dose from the Earth is measured within the radiation from nature in addition to the additional exposure dose due to the accident, 0.19 μSv + 0.04 μSv = 0.23 μSv/hour corresponds to an additional exposure dose of 1 mSv/y.

The above description is a simple estimation method based on assumptions on the safe side (i.e., conservative) in order to determine the scope of ICSA. Some opinion were expressed that the external dose received by an individual in actual life will be different from the estimated value, and generally can be

[38] MOE, "Radiation hazards based on the provisions of the Special Measures Law concerning the handling of pollution of the environment by radioactive substances released by nuclear power station accidents caused by the Tohoku Region Pacific Offshore Earthquake that occurred on March 11, Regarding the formulation of technical standards concerning prevention (consultation)" (November 22, 2011)

[39] Radiation Council, "Radiation hazards based on the provisions of the Special Measures Law concerning the handling of pollution of the environment by radioactive substances released by nuclear power station accidents caused by the Tohoku Region Pacific Offshore Earthquake that occurred on March 11, Regarding the formulation of technical standards concerning prevention (Report)" (December 13, 2011)

[40] MOE, " Additional radiation dose "1 mSv per year" concept " (October 10, 2011)

[41] MOE, NIRS, "Unified basic data on health effects etc. by radiation FY2016 edition"

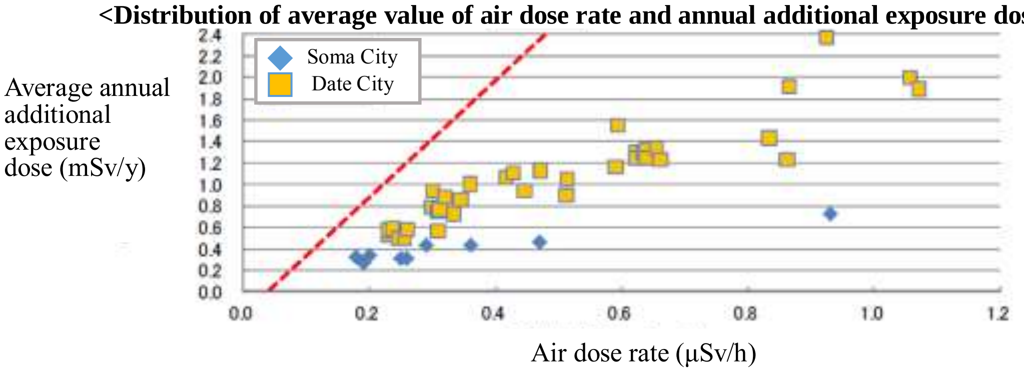
lower than the estimated value. The reason is that the time spent outdoors is often shorter than the hypothetical 8 hours in many cases, the indoor shielding rate differs depending on the type of building, etc. (e.g., coefficient of 0.2 in concrete construction), the air dose rate attenuates with the lapse of time, and it depends on where the individual stays and move around in daily activities.

| Commentary | Air dose rate and additional exposure dose received by an individual |
|---|---|

In Fukushima Prefecture, since FY2011, municipalities have measured the radiation doses using individual dosimeters, mainly for children and pregnant women. Looking at the correlation between the air dose rate (average) and individual additional exposure dose (average) in Soma City and Date City, even in areas where the average air dose rate exceeds 0.23 µSv/h, the average individual exposure dose may not exceed 1 mSv/y. (See the figure below.)

In addition, the radiation doses from the individual dosimeters measured in each municipality in Fukushima Prefecture in FY2012 were as follows: Hama-dori municipality A 0.4 mSv/y (estimated value by area air dose rate 2.9 mSv/y), Hama-dori municipality B 0.7 mSv/y (estimated value by area air dose rate 2.1 mSv/y), Naka-dori municipality F 0.6 mSv/y (estimated value by area air dose rate 2.4 mSv/y), Aizu district municipality P 0.2 mSv/y (0.7 mSv/y). These values are lower than the exposure dose estimated from the air dose rate, and it has been confirmed that there are large variations due to personal lives and behaviors.

**<Distribution of average value of air dose rate and annual additional exposure dose>**




* Based on the measurement of Soma City (elementary school students) and Date City (all ages)

* The dashed line shows the annual additional exposure dose estimated from the air dose rate.

Source: Discussion meeting with experts on decontamination - thinking from the past findings in the country and the four cities ~ Fact Book (August 1, 2014)