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Ten Years of Remediation Efforts in Japan

Outcomes of the Four IAEA–MOE Expert Meetings on Environmental Recovery of Off-Site Areas Affected by the Fukushima Daiichi Accident

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TEN YEARS OF REMEDIATION EFFORTS IN JAPAN

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TEN YEARS OF REMEDIATION EFFORTS IN JAPAN

OUTCOMES OF THE FOUR IAEA–MOE EXPERT MEETINGS ON ENVIRONMENTAL RECOVERY OF OFF-SITE AREAS AFFECTED BY THE FUKUSHIMA DAIICHI ACCIDENT

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For further information on this publication, please contact:

Section on Decommissioning and Environmental Remediation
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
Email: Official.Mail@iaea.org

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FOREWORD

The accident at the Fukushima Daiichi nuclear power plant led to radioactive contamination of large areas. The Government of Japan formulated a programme for the recovery of these areas and launched remediation efforts in affected off-site areas. The aim of the recovery strategy and the remediation programme was to improve the living conditions of the people affected by the accident.

In October 2011 the IAEA, at the request of the Government of Japan, conducted an international mission to Japan to support the remediation of large, contaminated areas outside the site of the Fukushima Daiichi nuclear power plant. In response to another request by the Government of Japan, in October 2013 the IAEA organized a follow-up international mission to evaluate the progress of the remediation activities implemented since the previous mission in October 2011.

The missions were conducted through the assessment of the information provided to the IAEA and utilizing professional and open discussions with the relevant national, prefectural and local institutions in Japan. For both missions, the findings were reported and advice was provided to the Government of Japan through the Ministry of the Environment of Japan.

Following the IAEA Action Plan on Nuclear Safety, the IAEA held four bilateral meetings with the Ministry of the Environment. The objectives of these meetings were to provide technical assessment by the IAEA experts on the progress of the off-site remediation activities undertaken by relevant authorities of Japan; provide advice and recommendations to the Ministry of the Environment on future remediation activities; and disseminate findings to the international community by publishing a summary report.

In these meetings it was agreed that the IAEA, in cooperation with the Ministry of the Environment, would prepare a consolidated report capturing the findings and information from the four meetings to produce a more detailed publication. This publication provides consolidated information on the different topics discussed during the above mentioned meetings, lessons identified and suggestions for future work.

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The IAEA officers responsible for this publication were H. Monken-Fernandes of the Division of Nuclear Fuel Cycle and Waste Technology and Y. Mori of the Division of Radiation, Transport and Waste Safety.

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1. INTRODUCTION

1.1. BACKGROUND

The accident at the Fukushima Daiichi nuclear power plant (NPP) in Japan occurred in March 2011 and was caused by a huge tsunami that followed a massive earthquake. It was the worst accident at a nuclear power plant since the Chernobyl accident in 1986.

The accident caused the release of radionuclides into the environment. It is reported that most of the atmospheric releases were driven eastward due to the prevailing winds and were deposited and dispersed within the North Pacific Ocean. However, due to the changes in the wind direction that took place on 12, 14 and 15 March, portions of the atmospheric releases were deposited on land, mainly in the north-westerly direction from the Fukushima Daiichi NPP.

Noble gases constituted a significant part of the releases from the Fukushima Daiichi NPP in the early stages. It is reported that between 6,000–12 000 PBq of ^{133}Xe have been released. The estimated total activity of ^{131}I released lies between 100–400 PBq, and for ^{137}Cs these values are 7–20 PBq. According to some authors quoted in the IAEA report [1], these values are roughly one-tenth of the releases from the Chernobyl accident in 1986. The largest long-lived contamination of ^{137}Cs took place to the northwest of the Fukushima Daiichi NPP. The total deposition of ^{137}Cs on the land surface of Japan was estimated to have been around 2–3 PBq.

Assessing the consequences of the accident, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [2] stated that “overall, the estimated doses received by the Japanese public were low, the radiation impact is also expected to be low”. It also indicated the unlikelihood that any increase in cancer rates due to radiation exposure would be discernible. This could be partially attributed to the evacuation orders declared shortly after the accident, to avert the exposure of people, but that does not mean that other consequences of a societal or psychological nature were negligible and should be disregarded. These will be dealt with further in this report.

After events that lead to the contamination of the environment, consideration needs to be given to the remediation of the areas affected by the accident. As stated in the IAEA Safety Glossary [3], remediation is “any measures that may be carried out to reduce the radiation exposure due to existing contamination of land areas through actions applied to the contamination itself (the source) or the exposure pathways to humans”. In the specific case of the Fukushima Daiichi NPP accident, attention also needed to be paid to the preparation for the return of evacuees to their homes (whenever possible). In this context, factors such as the restoration of infrastructure and the sustainability of economic activities at the community level were also considered. To this effect, and as described in the IAEA report [1], a remediation strategy[1] was put in place by the Japanese government. The strategy specified that residential areas, including buildings and gardens, farmland, roads and infrastructure — with emphasis on the reduction of external exposures — constituted the priority areas for remediation.

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[1] To be noted that prior to the Fukushima Daiichi NPP accident, policies and strategies for large-scale post-accident remediation were not in place in Japan. Therefore, there was a need to develop such policies and strategies in the period after the accident. Due attention will be paid to this aspect later in this report.

In the scope of this strategy, the Japanese Government, in August. 2011, classified the land to be remediated into:

- The Special Decontamination Area (SDA) – areas that almost overlapped with the evacuation zone within a 20 km radius of the Fukushima Daiichi NPP, and the earlier established 'Deliberate Evacuation Area' which were located beyond the 20 km radius from the plant where the additional annual dose for individuals could exceed 20 mSv in the first year after the accident. As part of the overall strategy, the Government had the responsibility of formulating and implementing remediation plans to be applied at the Special Decontamination Area;
- The Intensive Contamination Survey Area (ICSA) - areas that included municipalities where the air dose rate was 0.23 $\mu Sv.h^{-1}$ or more in some parts of the municipalities. Within these areas, municipalities were supposed to conduct monitoring surveys to identify those areas that would require remediation activities. The national Government was in charge of providing financial and technical support for the implementation of such activities.

Another important part of the Japanese strategy for remediation of the affected areas was the development of a number of pilot projects, conducted by the Ministry of Environment (MOE), the Japan Atomic Energy Agency (JAEA), academic institutions and other relevant organizations that initially performed a series of small-scale studies to assess the effectiveness of decontamination procedures applied to different types of surfaces (e.g. streets, roofs, walls and lawns). In subsequent investigations, the feasibility of decontamination of larger areas was considered. It is considered that such pilot studies played an important role in planning and implementing remediation strategies.

During these activities, the IAEA was called to provide technical support and expertise to Japan in different areas, remediation efforts included. The information was to be shared with the international community.

In 2011, in response to a request made by the Government of Japan, the IAEA organized a fact-finding Mission to support the remediation of large contaminated areas outside the site of the Fukushima Daiichi NPP. The Mission was carried out in the period of 7–15 October 2011. The Mission had three objectives:

- Provide assistance related to Japan's plans to remediate large areas contaminated by the Fukushima Daiichi NPP accident;
- Review Japan's ongoing remediation related strategies, plans and activities, including contamination mapping;
- Share its findings with the international community as part of the joint effort to broadly disseminate lessons learned from the accident.

The Mission included an assessment of the information provided, open discussions with relevant institutions in Japan, and visits to the affected areas, including several demonstration sites. The main findings and pieces of advice provided by the mission team were made public [4]. Three main recommendations were: 1) The Japanese authorities involved in the remediation strategy are encouraged to cautiously balance the different factors that influence the net benefit of the remediation measures to ensure dose reduction. They are encouraged to avoid over-conservatism which could not effectively contribute to the reduction of exposure doses. This goal could be achieved through the practical implementation of the Justification and Optimization principles; 2) It is important to avoid classifying as 'radioactive waste' waste materials that do not cause exposures that would warrant special radiation protection measures" The authorities were encouraged to "revisit the issue of establishing realistic and credible limits (clearance levels) regarding associated exposures", and 3) Authorities were also encouraged to "maintain their focus on remediation activities that bring the best results in reducing the doses to the public".

Team members were concerned about the potential risks of misunderstandings that could take place if the population were only (or mainly) concerned with contamination concentrations (i.e. surface contamination levels (Bq.m^{-2}) or volume concentrations (Bq.m^{-3}) rather than dose levels. The issue here was that the investment of time and effort in removing contamination beyond certain levels (the so-called optimized levels) from areas where the additional exposure was relatively low, would not automatically lead to a reduction of doses for the public. It also involves a risk of generating unnecessarily huge amounts of residual material. The use of the concept of decontamination underpinning the remediation works remained a big issue for the Japanese authorities and as a result, as it will be seen later in this report, the management of large amounts of generated wastes became a rather complex challenge to be faced by the Japanese organizations involved in the remediation works, mainly the MOE.

Two years later, 14–October 2013, a follow-up Mission was carried out with three specific objectives:

- To provide assistance to Japan in assessing the progress made with the remediation of the SDA (not included in the previous Mission of 2011) and the ICSA;
- To review remediation strategies, plans and works, in light of the advice provided by the previous Mission on remediation of large contaminated off-site areas;
- To share its findings with the international community as lessons learned.

The report produced by the mission team was made publicly available [5]. The mission team recognised that Japan made enormous efforts to implement the remediation programme to reduce exposures to people in the affected areas, to enable, stimulate and support the return of people evacuated after the accident, and to support the affected economic and social disruptions.

Key points raised during the Missions included the importance of communicating to the population the entire remediation and reconstruction programmes and how the various components interact with each other. An important point to be raised was the trade-offs between reducing exposure and increasing waste volumes.

It was believed that by pursuing this course of action the authorities would be contributing to reducing some uncertainties and would provide greater confidence in the decisions being made. It was firmly believed that by promoting a holistic view the authorities would also be facilitating the opportunities to plan key stakeholder engagement activities, allowing the process to be proactive rather than reactive. Another aspect that was highlighted and followed up the issue raised in the 2011 Mission, was the need to have in place a continued movement towards the use of the individual doses, as measured with personal dosimeters, to support remediation decisions. Authorities were also encouraged to establish a mechanism and platform for learning and sharing the lessons (knowledge management system) gained with the remediation efforts.

In 2013, the IAEA organized an International Experts Meeting on Decommissioning and Remediation after a Nuclear Accident. The event was organized in connection with the implementation of the IAEA Action Plan on Nuclear Safety. The resulting report can be found in Ref. [6]. The section on remediation covers the following topics: 1) Objectives of remediation; 2) Application of reference levels and standards; 3) Characterization and monitoring of the environment, 4) Dose assessment; 5)

Evaluating management options for remediation and 6) Developing and implementing remediation strategies.

Important points raised during the meeting by the international experts involved the understanding that there is a need to find the appropriate balance between a ‘technical’ (or numerical) approach and a ‘social’ approach for making decisions on remediation actions. It was proposed that further guidance on integrating and optimizing both approaches be developed. It has also been recognised that clear guidance in support of the implementation of the (safety) standards and on reference levels in specific situations should be developed. It has been recognised that inadequate attention to temporal and spatial variation in the environmental behaviour of deposited radionuclides can lead to estimates of doses which are inaccurate and may overlook areas or pathways causing higher doses. It has also been determined that there is a need to improve dose assessment models using site-specific information gathered during characterization and monitoring and taking account of recent scientific progress. Attention was also paid during the experts' meeting to decontamination aspects. On this topic, it was endorsed that decontamination can constitute an important part of remediation for areas affected by nuclear accidents. However, as in the two IAEA Missions carried out in Japan, it was considered that as long as decontamination techniques can be readily applied for small inhabited areas, their use for large areas of contaminated agricultural land raises significant challenges regarding waste disposal and the associated costs. Also, and in alignment with advice provided by the experts in the Missions to Japan, the notion that remediation should not be considered as decontamination only was shared. In this regard, the use of other methods could be more beneficial to achieve the desired objectives.

Two other important points raised during the Experts’ Meeting in 2013 dealt with Stakeholder Engagement and Knowledge Management – both topics are covered in this report. At first, it was pointed out that stakeholder participation is of fundamental importance to ensure that sustainable decisions are made. It is proposed that decisions taken, and solutions derived with stakeholder involvement are the ones most likely to succeed. On knowledge management, experience has shown that knowledge gained from post-accident remediation needs to be recorded, catalogued, easily retrievable, and made available to an international audience, so that it can be readily accessed and applied to future events.

In 2015, the IAEA published the ‘The Fukushima Daiichi Accident’ set of reports, consisting of a Report by the IAEA Director General and five technical volumes [7]. It was the result of a comprehensive international collaborative effort that involved five working groups with about 180 experts from 42 Member States and different international organizations. The five volumes provide a description of the accident and its causes, evolution and consequences.

The fifth volume ‘Post Accident Recovery’ [8] is composed of five sections. 1) Background to Post-Accident Recovery. 2) Remediation. 3) On-site Stabilization and Preparations for Decommissioning. 4) Management of Contaminated Material and Radioactive Waste. 5) Community Revitalization and Stakeholder Engagement. The second, fourth and fifth sections are particularly relevant to this report.

After the two IAEA Missions to Japan, it was concluded that it would be appropriate that instead of conducting lengthy missions with a large number of experts to cover the many different aspects involved in a remediation programme of this size, it would make much more sense to conduct smaller meetings dedicated to discussing a reduced number of topics per meeting but allowing for more in-depth exchange of experiences and views. Therefore, these bilateral discussions provided the opportunity to examine in detail many aspects related to the remediation of the off-site areas affected by the accident, producing four summary reports each one issued after an individual meeting. In 2016 and 2017 four meetings (two each year) involving Japan MOE staff members and the IAEA designated experts plus IAEA staff members were implemented. In addition to the roundtable discussions, these meetings also included site visits and discussions with local (municipalities) officials as well as staff members of contractors working for the MOE.

This report contains the summary of the discussions with the addition of current information to reflect the most updated status of the remediation works going on in the areas affected by the Fukushima accident. The report also marks the 10th Anniversary of the Fukushima Accident.

1.2. OBJECTIVE

As mentioned above, upon completion of the fourth of IAEA–MOE bilateral meetings, it was agreed that a broad range of information had been accumulated and that it would be worth, and indeed very opportune, to synthesize all that knowledge in a dedicated report to be published by the IAEA to the benefit of the Japanese organizations and institutions and the overall Japanese audience as well as the broad international community.

With the above in mind, the objective of this report is to consolidate the discussions held in the 4 IAEA–MOE meetings on real experience gained with the remediation of off-site areas affected by the Fukushima Daiichi NPP accident, capturing the main points covered in these discussions to disseminate the information and lessons learned within Japan and to the wide international community.

1.3. SCOPE

The report covers the points that were dealt with during the discussions between the MOE and the IAEA (experts and staff members) and revolved around the following topics: i) policy and regulatory issues; ii) remediation, iii) waste management, iv) stakeholder engagement, v) knowledge management, and vi) recovery and revitalization. Each one of these topics will be dealt with in a dedicated section highlighting at the end of each section the outstanding lessons learned and recommendations for future studies and future developments.

1.4. STRUCTURE

The report contains nine sections. In Section 1, the background to the report is provided with a compilation of relevant initiatives put in place by the IAEA to cooperate with the Japan efforts dedicated to the remediation of off-site areas affected by the Fukushima Daiichi NPP accident. Section 2 provides a review of the scientific literature pertaining to the aspects that are relevant to the subject of environmental remediation with emphasis on topics that are significant to the situation in Japan. Section 2 is not meant to be a comprehensive review, instead it has the intention of offering some perspectives that complement the points that were discussed during the bilateral meetings. Section 3 covers policy and regulatory issues that underpinned the overall activities implemented in the scope of the remediation activities. Section 4 deals with the remediation activities indicating the approaches that were used, the results obtained, and an analysis on the effectiveness of these measures ending with a set of lessons learned.

Section 5 examines the waste management aspects associated with the remediation works, discussing the experiences and challenges faced in the process, the role played by the temporary storage sites and the one to be played by the Interim Storage Site. It discusses the issues related to the transportation of the residual materials generated and approaches used for soil recycling and the plans for final disposal. The section finally presents the lessons learned with the management of wastes generated with the remediation works. Section 6 covers stakeholder related issues presenting the approaches that were used in this regard while offering international perspectives on the topic. Section 7 covers knowledge management (KM), highlighting the importance of adopting such practices in the remediation programmes having in mind the contribution to others that may need to deal with similar tasks. Section 8 sheds light on the efforts dedicated to the recovery of the affected areas including aspects related to the infrastructure, securing the safety of food products and providing an overview of the regeneration project. Section 9 contains conclusions as a collection of lessons learned summarizing the most important points arising from each of the sections.

2. BRIEF LITERATURE REVIEW

2.1. INTRODUCTION

A nuclear accident that affects large areas is an event that triggers a lot of considerations regarding the actions implemented in the course of the response to the accident itself and during the post-accident phase in the short, medium and longer term. Different studies of technical and scientific nature, focusing on a wide range of aspects raised by the event have since been produced. This section is aimed at reviewing some of the research work published in scientific journals to set the scene, i.e. the position of the international scientific community on the different aspects related to the remediation (and remediation related issues) of the areas affected by the Fukushima Daichi NPP accident. It is not intended to be a comprehensive review, and additional work will be dealt with in other sections of this report. Instead, it provides information that will be useful to understand the results of the work developed by the MOE in dealing with the consequences of the accident.

2.2. MAIN POINTS OF CONSIDERATION

Before the accident approximately 78 000 people had been living in what became the 20-km 'Restricted Areas' and about 62 000 people were living between 20 km and 30 km of the plant (the Evacuation Prepared Areas in Case of Emergency). About 10 000 people were evacuated from the 'Deliberate Evacuation Areas' beyond the 'Restricted Areas' [9]. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) report gives the total number of evacuated persons as approximately 118 000 [2].

Efforts have been made to compare the environmental impacts of the Chernobyl accident and the Fukushima Daiichi NPP accident [10]. It was proposed that the consequences of the Chernobyl accident, in terms of radioactive material release, clearly exceeded those of the Fukushima Daiichi NPP accident. In the case of the Chernobyl accident, a total release of 5,300 PBq (excluding noble gases) has been estimated while for Fukushima the total release has been estimated at 520 (340–800) PBq. In addition to this major difference, is suggested that during the Fukushima Daiichi NPP accident, most of the radioactive released i.e. more than 80%, was transported offshore and deposited in the Pacific Ocean. The highly contaminated areas and the evacuated areas are smaller in the case of the Fukushima Daiichi NPP accident compared to the Chernobyl accident. In Fukushima, the total ^{137}Cs deposition onto the land was estimated as 2,482 TBq (2.48 PBq) based on the reconstructed fallout map [11]. According to the same authors, Fukushima Prefecture accumulated 1,992 TBq of ^{137}Cs while Tochigi and Ibaraki Prefectures accumulated 161 TBq and 118 TBq of ^{137}Cs, respectively; and total ^{137}Cs deposition in all the remaining prefectures was less than 100 TBq. Forests were the areas most affected by the deposition of ^{137}Cs, accumulating a total of 1,789 TBq of ^{137}Cs. The deposition of ^{137}Cs onto agricultural fields was 270 TBq and 199 TBq for paddies and other farmlands, respectively. That implies that the forest accumulated 72% of the total ^{137}Cs deposited on land [10].

It has been suggested in Ref. [12] that the average air dose rate decreased to about 20% of the initial value during the period from June 2011 to August 2016. The decrease was attributed to the radioactive decay of ^{134}Cs with a half-life of 2.06 y. The authors suggest that the air dose rate reduction was faster than was expected, considering only the decay of caesium, by a factor of about two. Evidence is offered indicating that the movement of radiocaesium in the horizontal direction was relatively small.

The decrease of Cs activity concentrations in soils is a function of vertical and lateral migration of the radionuclide. It has been observed that after the Tropical Storm Etau in 2015, dose rates decreased sharply for floodplain sections with high sedimentation because the topsoil layer, with high radionuclide contamination, was eroded and/or buried under cleaner fresh sediments produced mostly due to bank erosion and sediments movements [13]. These authors also propose that due to more precipitation, steeper slopes, higher temperatures and increased biological activities in soils, the reduction in radiation levels in Fukushima associated with vertical and lateral radionuclide migration was faster than that following the Chernobyl accident; because of that, monitored natural attenuation, along with appropriate restrictions, may be seen as the optimal option for water remediation in Fukushima contaminated areas. Additional evidence of the general downward trend in activity concentrations of radiocaesium is also offered in Ref. [14]. The authors took soil samples from unremediated locations within Fukushima Prefecture in June 2013 and July 2014 with a special focus on the Fukushima exclusion zone. Maximum activity concentrations of ^{137}Cs in soils were observed in the close vicinity of the Fukushima Daiichi NPP, reaching a value of 10^6 Bq.kg^{-1} in 2013. One year later these maximum levels decreased by a factor of at least 5.

As the ^{137}Cs activity concentrations in soils decreased, the exchangeable ^{137}Cs fraction in the soil also decreased, probably because of its adsorption by clay minerals, which limits mobility overtime after deposition onto the soil. It is well known that soil organic matter and clay minerals act as ligands for caesium, particularly the 2:1 layer-type silicates that retain caesium more strongly than other ligands [15].

Temporal changes were also assessed based on the ambient dose rate in forest environments in Fukushima Prefecture. It has been observed that the ambient dose rate varied among different forest types [16]. Again, it has been noticed that the ambient dose rate decreased faster than that induced solely by the physical decay of radiocaesium, and these variations were attributed to differences in the initial canopy interception of atmospherically deposited radiocaesium and the subsequent transfer from the canopy to the forest floor [16].

The behaviour of ^{137}Cs in freshwater systems has also been investigated. It has been found that, on average, particulate ^{137}Cs concentration accounted for 71–90% of the total amount of ^{137}Cs in the examined water samples. The distribution coefficient, K_d of ^{137}Cs varied in the range between 1.3×10^5 and 6.2×10^5 L/kg [17]. Another study investigated the radiocaesium concentrations in suspended and deposited sediments suggesting significant correlations of ^{137}Cs to total organic carbon [18]. That finding led the authors to propose that the organic fraction was the main phase that carried the radiocaesium in deposited sediments and in suspended sediments for suspended loads less than 25 mg.L^{-1}. On the other hand, for higher suspended loads e.g. those occurring during typhoon periods, the mineral fraction was the main carrier phase. The relevance of this finding is related to the fact that organically bound ^{137}Cs might give rise to significant sources of bioavailable radiocaesium for living organisms at Fukushima.

Although not an objective of the efforts of the MOE in terms of remediation, and therefore beyond the scope of this report, it is also useful to share some information on the behaviour of ^{137}Cs in the marine environment. Monitoring results from the Fukushima Prefecture showed that percentages of samples with activity concentrations values higher than the Japanese regulatory limit of 100 Bq/kg were more relevant for demersal fishes in comparison to pelagic fishes or other taxa [19]. Statistical analyses of results of ^{137}Cs in sediments revealed that the radionuclide activity concentrations, inside and outside the Fukushima Daiichi NPP port, decreased exponentially with time. These results allow to state that the contamination level of marine products in the Fukushima Prefecture, even within the 20 km radius area, has decreased drastically during the five years after the Fukushima Daiichi NPP accident, although ^{137}Cs concentrations higher than 10 kBq/kg$_{\text{(wet weight)}}$ were still detected in some specimens of sedentary rockfishes (*S. cheni*, *Sebastes oblongus*, and *Sebastes pachycephalus*) in the Fukushima Daiichi NPP port [18].

In terms of decontamination works, it has been observed that the decrease of the air dose rate was larger on asphalt pavements than on the soil surface while air dose rate near forest decreased slower than in an open field. These results also suggest that the air dose rate in urbanized areas can decrease faster than it is the case with land used for other purposes, even after decontamination. Finally, the air dose rate decrease after decontamination was slower than before decontamination [20]. Large amounts of radiocaesium deposited in the urban area were removed by initial run-off and the following wash-off effects due to rainfall during the four years after the accident, even without decontamination. The surface materials largely affect the removal of radiocaesium from urban areas and significant differences between the removal of ^{137}Cs on surfaces in Europe and Japan were observed [21]. The cost-effectiveness of decontamination of forest areas in Fukushima Prefecture was also assessed. It has been revealed [22] that decontamination costs for forested areas within 20 m of habitation areas varied in the range of US $23 billion−51.2 billion with a resulting reduction in annual external dose of about 2,500 person-Sv. The transport, storage, and administrative costs of decontamination waste and removed soil reached US $15.5 billion−21.2 billion. The authors concluded that, although implementing decontamination of all forested areas provides some major reductions in the external radiation dose for the average inhabitant, decontamination costs could potentially exceed US $140 billion.

These results indicate that technologies for reducing the volume of decontamination waste and removed soil, as well as the side effect on the forest ecosystem need to be considered and that further discussions about forest decontamination policies are needed. Implementation of agricultural countermeasures to reduce the contamination of rice plants (e.g., topsoil removal and fertilizer application on radiocaesium uptake by rice plants) was investigated over four years [23]. The results indicated that the topsoil removal was effective to mitigate the accumulation of radiocaesium in rice plants but the ratio of radiocaesium activity concentration between rice plant and soil increased. The reason for that was attributed to the radiocaesium imported from irrigation water and the relatively high exchangeable radiocaesium proportion in the top layers of ploughed paddy soils. It has also been observed that increasing potassium and reducing nitrogen fertilizer in the soil tended to inhibit the radiocaesium uptake by rice plants. Finally, from all the countermeasures applied in the paddy fields, it has been assessed that the most effective one was the application of phlogopite, although some additional results are needed to confirm the effectiveness of the application of phlogopite considering the limited available information [23].

A comprehensive review of the characteristics and capabilities of technologies used in decontamination processes was produced [24]. The review also covered logistical considerations of implementation of the technologies, including waste management. One of the reported findings concerns the decontamination efficiency of soluble radionuclides adhered to hard surfaces. In these cases, established physical cleaning methods generally have low (< 50%) decontamination efficiencies. The authors raise the point that even modest efficiency in decontamination may be relevant to allow workers to operate in contaminated areas for extended periods. It is also pointed out that temporary high-volume waste storage capacity will likely be a key factor in early implementation.

Among the decontamination technologies with high throughput for physical removal, fire hosing may be the most efficient high-volume particulate removal; with reported removal efficiencies in the range of 60–70% removal (a decontamination factor (DF) of 2.5–3.3). The drawback of such a technique is high liquid waste volumes and secondary contamination risks. The throughput of some methods such as street sweepers can be high (i.e., hundreds of square meters per hour). Vacuum street sweeping and washing are to be highlighted. They are common techniques and in addition to these, pre-trained operating personnel might be easily made available, something that would allow for early implementation. Vacuum sweeper fleets can be accompanied by a global positioning system (GPS).

This feature will contribute to the logistics of their deployment. The authors also examined the shot blaster technique, which also provides higher asphalt road coverage rates (at a rate between 300–3500 $m^2 \cdot day^{-1}$). However, as with street sweepers, particulate-based removal efficiencies are lacking. For other types of contaminants, values between 60–95% efficiency have been reported, depending on operations.

Operating costs of the above-mentioned techniques are reportedly low (typically of the order of tens of cents to several $dollars.m^{-2}$). On the other hand, the capital cost and delivery times can be significant, especially if the machinery is unavailable nearby. Shot blasting equipment coupled with vacuum capabilities is somewhat cheaper to acquire than street sweepers but can be at least an order of magnitude higher in terms of labour costs (i.e., of the order of several $dollars.m^{-2}$). It is likely that sweeping and blasting methods will need multiple applications. Another reported constraining factor is that it is limited to smooth, dry, undistorted and/or undamaged roads. As mentioned above temporary high-volume waste storage facilities are likely to be a key factor in early implementation.

According to Ref. [24], some techniques will present lower throughput capacity (of the order of hundreds of square feet per hour). That is because they will involve more manual labour, physical methods removing a thin surface layer (e.g. blasting, grinding). On the positive side, they can generally provide higher (up to ~90% or DF ~10) decontamination efficiencies. Washing and sandblasting methods can generate significant secondary waste (e.g. contaminated wastewater and grit material), while others like grinding and shaving produce minimal additional waste. Among the techniques that involve chemical treatment, e.g. coatings or foams for porous hard surfaces, the removal efficiencies can vary quite significantly with a minimum DF around 2, with higher values being observed for non-porous surfaces like painted carbon steel (~11). Available treatment rates were in of the order of $m^2 \cdot h^{-1}$. Strippable coatings have demonstrated efficiencies as high as 81–94% in terms of loose particulates removal and can be applied to a wide variety of porous and non-porous hard surfaces. Tens of $m^2.day^{-1}$ application rates can be achieved.

However, drying and curing times may be significant, and multiple applications may be required. Fixed coatings, specifically the application of a thin layer of about 5 cm of concrete, implying in 67% dose reduction of ^{137}Cs surface concentration, could be a relatively high-throughput and low-cost technology. The efficiency of dry vacuum cleaning of bricks and concrete can be as low as ~20–45% of loose < 2 μm particles. HEPA-filtered vacuums can imply high capital and operational costs. Despite that, some models will permit multiple workers to operate on a single unit. Note that high-pressure washing can demonstrate relatively low effectiveness and may need very slow sweep rates to reach high efficiency (45–90% at 0.2–10 $min.m^{-2}$, respectively). In addition, high-pressure washing may require significant preparation for contaminated water runoff collection. Like road sweepers, resurfacing and repaving of contaminated surfaces is an established approach with known throughput rates and in some situations limited (although potentially beneficial) dose reduction potential (50–75% dose reduction by applying 5–6 cm of asphalt). The disadvantage is the long-term concerns regarding the potential for re-exposure or migration of the original contamination as the applied asphalt ages and/or wears. Experience from work in the neighbourhood of the Fukushima Daiichi NPP shows that exposures from roadside soil and vegetation can be significantly reduced by eliminating a thin layer of contaminated soil after the removal of overlaying vegetation. Trimming and mowing of vegetation provided widely varying results (~10–90% dose reduction), but burial or removal of centimetres-deep surface soil (e.g. tillage and stripping, respectively) provided DF greater than 2.8 (~65% reduction).

Regarding insoluble radiological particulate decontamination, the few high-throughput technologies (e.g. fire hosing, vacuum street sweeper and washers, shot blasting) presented similar maximum decontamination efficiencies (e.g. DF up to 3.3, or 70% removal). On the other hand, they indicated almost no efficacy in some situations. Fixed coatings, mainly the application of a thin concrete layer (e.g. 5 cm), could in principle become a relatively high- throughput and low-cost technique. Sandblasting of open areas (e.g., concrete floors, roofs) has shown relatively high treatment rates (hundreds of $m^2.day^{-1}$). Strippable coatings have demonstrated relatively high (81–94%) loose particulates removal and apply to a variety of porous and non-porous hard surfaces at lower area throughputs. The technologies that do not cover a large surface area quickly for particulate contaminated surfaces (dry vacuum cleaning, high-pressure washing) generally show higher decontamination and require waste collection and handling.

Putting in place such large extent remediation (decontamination) measures, associated with the initial relocation of thousands of people, leads to impacts of social dimensions. It has been suggested that mass relocation after the Fukushima Daiichi NPP accident might not have been the optimal policy response [9]. In the assessment, the authors used the so-called ‘J-value’ analysis and showed that the relocation option was not justified even for the most contaminated areas of Tomioka and Okuma. The authors also suggested that relocation has produced undesired effects that include a fall in the notional life quality of the residents of these towns. They also mentioned that the very extensive population relocations put in place in the months and years following the Chernobyl accident set a precedent. It has been suggested that management of social identity in addition to social support is important for mitigating psychological distress after a nuclear accident, and that support for individuals should be focused on the management of both host and evacuee communities in relocation areas [25].

The economics of radioactive decontamination has also been assessed [26]. It has been proposed that it may be optimal to have different policies for urban land and farmland, with greater delay for decontamination of the latter. Having said that, the author recognizes that it may not be optimal if the presence of nearby, untouched farms and woodland has significant negative effects on resident's mental health. The value of resettling relatively lightly contaminated lands first and delaying resettlement of areas with higher radiation levels (e.g. above 100 mSv/a) is also noted. Attention is called to the role of fear, anxiety and dread in resettlement and decontamination decisions.

Many former residents of the evacuated zone in Fukushima have significant fears about moving back, even after decontamination. On the other hand, it is recognized that there may be significant discontinuities in the benefits if radiation levels are completely restored to prior levels.

From a purely monetary point of view, major long-term accident consequences can be quantified using the cost per severe accident. In addition, the change of each consequence can be captured over time. In this regard, it has been proposed that even though decontamination contributes to a large share of the cost per severe accident, decontamination associated monetary[2] impacts significantly decrease after several years [27].

The discussion in the above paragraph does not consider less tangible elements of social and psychological nature; however, it does imply that important considerations need to be paid to stakeholder engagement in the decision-making process and policy elaborations in the context of environmental remediation. A combination of civic involvement in the decision-making process will help the process of public engagement. However, it is suggested that because of difficulties in the two-way communication in the policy-making process and the lower level of scientific understanding, as are seen in Japan, that public engagement in nuclear policy on a well-grounded and

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[2] Monetary value of decontamination (MD) is the sum of the decontamination cost (DC), and the waste management cost (WMC)

democratic basis would be still difficult to be achieved at present [28]. It was recommended in Ref. [28] that a shift of policy decision process from the top-down approach to the bottom-up approach for promoting public engagement would be required with the aim of improving democratic legitimacy and trust in the central government. Civil groups in the ASEAN[3] arrangement have been developed with having rights to oppose the government decision, but policy making has been processed under the control-oriented approach leading to difficulties in public engagement.

In the context of stakeholder engagement and in the scope of the Fukushima Daiichi NPP accident, it is not possible to skip the concept of 'citizen science'. This remains a vaguely described concept. One possible definition is that it is a part of Open Science in which citizens can participate in the scientific research process in different ways: as observers, as funders, in identifying images or analysing data, or providing data themselves; the objective being the democratisation of science. It is also linked to stakeholders' engagement and public participation. In the context of the Fukushima accident the SAFECAST project [29] represented "an innovative model of rapid, integrated, open development, simultaneously addressing requirements in several disparate fields, including hardware design, software design, engineering, radiation science, visual design and communication, and social design factors". The main objective of the project was to provide information to the wider public, in an easily accessible way e.g. maps and other visualizations. That effort was the result of the perception that data relative to the accident were not properly or transparently communicated by official organizations. As a result, a portable detector kit was designed and citizens using the detector were able to gather the intended information themselves and report back to a database that ended up containing millions of data.

It has been raised in the research community that whereas the decision-making process guided by the principles of radiation protection of Justification and Optimization is intended to include non-radiological factors, in reality, implementation of these principles ends up being driven essentially by radiological considerations. By pursuing this approach, it is possible to overlook the indirect effects of exposures to radiation in the scope of an emergency (eventually post-accident) situation. These indirect effects can include, but will not be restricted to, severe depression and suicides. In this context, the SHAMISEN project – funded by the European Commission within the OPERRA project – was conceived to develop a suite of recommendations, to improve preparedness and health surveillance of populations affected by previous and future radiological accidents [30]. Specific recommendations for supporting dose assessment at different phases of the accident (including the remediation phase), improving estimates of radiation risk, and enhancing the wellbeing of the affected populations according to their needs and without generating unnecessary anxiety were provided [31]. The project divided a radiological accident into three phases: preparedness, the early and intermediate phase, and long-term recovery. Relevant to this report are the recommendations made by the project regarding the third phase involving remediation. These recommendations were:

- Have plans for the lifting of evacuation as soon as possible (associated to evacuation);
- Build networks of experts – local facilitators – population (associated to communication and training);
- Consider the preferences of people living in affected areas (associated to communication and training);

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[3] The Association of Southeast Asian Nations (**ASEAN**) is a regional grouping that promotes economic, political, and security cooperation among its ten members: Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam.

- Foster long-term participation of affected populations and communities (associated to communication and training);
- Continue dose assessment for workers and affected population (associated to dosimetry related actions);
- Continue dose measurements support to populations (associated to dosimetry related actions);
- Expand support of populations to consider economic and social upheavals (associated to health surveillance actions);
- Launch systematic health screening based on appropriate justification and design (associated to health surveillance actions);
- Clarify objectives and expected results of epidemiological studies; Ensure long-term sustainability of follow-up of populations at risk (associated to epidemiological studies).

2.3. MAIN LESSONS FROM THE LITERATURE REVIEW

The points covered in this section can be seen as a brief scene-setting for the in-depth discussions to be presented in the subsequent sections of this report. They present the perspectives shared within the international scientific community by different authors covering areas that were dealt with during the remediation works in Japan and discussed in the scope of the four IAEA–MOE meetings.

It has been established that air dose rate reduction was faster than expected, considering only the radioactive decay of caesium. That faster decrease in the air dose rate resulted from a combination of natural processes and remediation measures. Because of that, some authors see that the monitored natural attenuation, along with appropriate restrictions, may be seen as the optimal option for water remediation in contaminated areas in Fukushima. Alternatively, different policies for urban land and farmland could have been considered, with greater delay for decontamination of the latter. With that said, decontamination activities are responsible for a large share of the cost per severe accident, however, decontamination associated monetary impacts significantly decrease with time.

An extremely important point of discussion in the scientific community has to do with the decision-making process. In this regard, the combination of civic involvement in the decision-making process and the degree of scientific literacy was reported as essential components to sustain appropriate public engagement. Associated with that, a shift of policy decision process from the top-down approach to the bottom-up approach for promoting public engagement has been suggested with the aim of improving democratic legitimacy and trust in the central government. With that said, it is important to keep in mind that the decision-making process, framed by the principles of radiation protection of Justification and Optimization are meant to consider radiological and non-radiological factors. In practice, however, their implementation ends up being driven to a large extent essentially by radiological considerations.

After this brief review of the scientific literature on topics that are relevant to the scope of the subjects dealt with in this report, the following sections will focus on the outcomes of the discussions between international experts and MOE staff members in the scope of the four bilateral meetings (held in 2016 and 2017) and further exchanges.

3. POLICY AND REGULATORY ISSUES

3.1. INPUTS FROM IAEA–MOE MEETINGS ON REGULATORY ISSUES

In the third of the IAEA–MOE meetings it was agreed that it would be appropriate to start a process to review the national policy on environmental remediation (Act of Special Measures) [31] in a way to provide alignment with IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [32], specifically by addressing the requirements for existing exposure situations. In this regard, the accumulated national experience would also be captured in reviewing the Act of Special Measures [31]. The IAEA team also advises that due consideration be given to enhancing the dialogue/interaction among the national government, Fukushima prefecture and municipalities concerned. In conversations of the team with municipal authorities, it has been understood that different regulatory levels were the cause of some confusion. Particularly, at the fourth meeting, the reason why removed soil could not be used in reconstruction instead of being moved as waste was discussed. That triggered a recommendation of the team of experts that the MOE should continue working on gathering technical and safety data and specifications with other relevant agencies for potential options of soil recycling/reuse. In doing so, inputs from other stakeholders should be sought to form the basis of policy options that would ensure the protection of public health and the environment.

3.2. EVACUATION ORDER

Following the accident, on March 11, 2011, the Central Nuclear Emergency Response Headquarters (NERHQ) was established in the Prime Minister's Office. Based on the orders issued by the NERHQ, the Governor of Fukushima and other municipal governments made residents living within a 3 km radius of the Fukushima Daiichi NPP evacuate and instructed the residents living within a 10 km radius to stay indoors. On March 12, 2011, it was additionally established that all residents living within a 20 km radius of the Fukushima Daiichi NPP would need to evacuate: that area which was later designated as the 'Restricted Area' [33].

Specific areas beyond a 20 km radius of the Fukushima Daiichi NPP, where the external dose could reach around 20 mSv/a were designated as the 'Deliberate Evacuation Area' on 22 April 2011 and residents living in these areas were requested to evacuate within one month [33].

Immediately after the accident, evacuation areas were determined following the disaster prevention guidelines stipulated in the 'Emergency Preparedness for Nuclear Facilities' [33]. However, it did not assume the long-term evacuation, but an evacuation over a short period or indoor sheltering. Afterwards, the lower end of the reference level range of 20–100 mSv/a, which is supposed to be applied under the emergency exposure situations based on the International Commission on Radiological Protection (ICRP) recommendations,[32] was applied as a standard value for the evacuation

In addition, the 'Evacuation-prepared Area in Case of Emergency' was established between 20 km and 30 km of the Fukushima Daiichi NPP, where people were required to prepare for sheltering indoors or evacuating in case of emergency [33].

The designation of this area was lifted on 30 September 2011, following the stabilization of the cooling systems of reactor cores in Fukushima Daiichi NPP units 1 –3, and the completion of Step 1 of the roadmap toward the end of the Fukushima Daiichi NPP accident. The area of the evacuation was reviewed a couple of times but the 'Restricted Area' and 'Deliberate Evacuation Area', later laid the basis for the 'Countermeasure Area' and the SDA [33].

3.3. THE TRANSITION OF THE EVACUATION AREAS

With time, the overall situation improved significantly, due to the progress observed towards the decommissioning of the damaged Fukushima Daiichi NPP and the reduction of air dose rates because of a combination of natural decay and implemented decontamination projects.

On 16 December 2011, the NERHQ confirmed the completion of Step 2 of the roadmap published by the TEPCO on 17 Apr. 2011. On 26 Dec. 2011, the NERHQ published the 'Basic Concept and Future Tasks for the Review of the Restricted Area and Deliberation Evacuation Area Under After the Completion of Step 2'[33]. The basic concept reviewed the evacuation areas, with the intent of lifting evacuation orders in areas with low dose rates after the decontamination activities.

Based on this concept, the evacuation zone under evacuation orders was to be re-organized into the following new 3 categories, according to the measurement of exposure rates [33]:

- The Difficult to Return Zone (DRZ);
- The Habitation Restricted Areas;
- The Preparation Areas for Lifting of Evacuation Orders.

Areas were categorized as the DRZ if the doses exceeded 50 mSv/a at that time and would likely exceed 20 mSv/a even after 5 years. Areas were categorized as the Habitation Restricted Area if the doses exceeded 20 mSv/a at that time. Areas were categorized as the Preparation Area for Lifting of Evacuation Orders were those where it has been confirmed that annual accumulated doses would surely be below 20 mSv and efforts were to be made for early return of residents. Passing on major roads and temporary return of residents were flexibly permitted. Physical protection measures, such as screening and dose management, were not necessary in principle upon temporary entry [33].

3.4. TARGET

In 'The basic idea on radiation protection for the future lifting of evacuation orders and reconstruction', published on 19 July 2011, it was stated that "As a reference level for the optimization of radiation protection strategies, a lower dose in the range of 1 to 20 mSv.a^{-1} will be chosen, which is applied under the existing exposure situation based on the ICRP's recommendations. An intermediate reference level can be adopted and reviewed according to the gradual improvement of the situation, but as a long-term goal, the 1 mSv/a value is supposed to be selected" [33].

This annual effective dose of 1 mSv was incorporated in subsequent documents, such as the Basic Policy for Emergency Response (26 August 2011) and the Basic Policy based on the Act on Special Measures Concerning the Handling of Environmental Pollution (11 November 2011) [31]. This long-term target was aimed to be achieved by whole radiation protection policy, not only by remediation but also by other factors (e.g. natural attenuation of radionuclides, weathering effects, reducing the internal exposure by food safety management).

3.5. THE ACT ON SPECIAL MEASURES CONCERNING RADIOACTIVE MATERIALS

Remediation activities were launched immediately following the accident at the Fukushima Daiichi NPP. Parents of students in local schools took the task into their own hands voluntarily.

On 30 August 2011, 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 was promulgated.

3.5.1. Establishment of the Act on Special Measures Concerning Radioactive Materials

The Act was promulgated on 30 Aug. 2011[4]. The purpose of the act was to provide for the prompt reduction of the radiological impacts associated with the accident by instituting measures to be attributed to the national and local governments as well as to the relevant nuclear operator. This Act was the main instrument adopted by the Japanese government to deal with the remediation programme of the areas affected by radioactive pollution and was taken into effect on 1 January 2012. From this point in time, basic institutional arrangements have been established to implement large-scale decontamination activities.

The Act established, among other things, the main purposes of the remediation programme; the distribution of roles and responsibilities among the involved institutions, namely the central government and prefectural and municipal governments; the role of stakeholders; basic lines for monitoring, decontamination, and waste management; and the provision of financial resources.

Under the Act on Special Measures Concerning Radioactive Materials, the MOE was assigned as the leading Ministry for implementing the decontamination activities in cooperation with other relevant organizations. The roles and responsibilities of the other relevant organizations were also established in this Act. The MOE would also be responsible for developing the basic principles regarding the handling of environmental radioactive pollution.

On 14 December 2011, the MOE published the Decontamination Guidelines, in the wake of the pilot project conducted by the JAEA and other authorities (see Section 4 on Remediation), decontamination methods and other relevant information were systematically compiled in preparation for the enforcement of the Act. The guidelines described in detail the activities to be implemented in every single stage of the decontamination process, such as monitoring implementation, transportation, waste management, etc.

These guidelines were updated as necessary to reflect the knowledge and experience obtained during the decontamination activities and to incorporate new techniques and technologies used in the decontamination process according to the inputs provided by experts and members of the local governments. As for the matters such as the storage and treatment of waste contaminated with radioactive materials from the accident, the Waste Management Guidelines were published on 27 December 2011 (See Section 5).

The Act also attributed competence to the MOE to set standards for the decontamination and disposal of waste, soil, etc., contaminated with radioactive materials. In terms of decontamination the following responsibilities are to be mentioned:

- Give due consideration to the degree of contamination in designated areas where the national government must carry out measures for decontamination;
- Develop a plan to carry out decontamination measures;
- Secure and construct the Temporary Storage Sites (TSSs) and the Interim Storage Facility (ISF) to store the wastes arising from decontamination activities.

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[4] Here after referred to as the ‘Act on Special Measures Concerning Radioactive Materials’

In terms of disposal of wastes, the MOE was tasked with the following activities:

- Designate areas where wastes need to be treated under the direct control of the national government;
- Designate wastes that exceed pre-specified levels of contamination (8,000 Bq/kg);
- Develop a plan regarding the management of wastes (storage and disposal). FIG. 1 presents an outline of the implementation of the Act on Special Measures Concerning Radioactive Materials.

3.5.2. Basic Policy of the Act on Special Measures Concerning Radioactive Materials

In response to the establishment of the Act on Special Measures Concerning Radioactive Materials in August 2011, the Committee on Environmental Remediation was launched in September of the same year to discuss matters pertaining to remedial actions to be conducted under the responsibility of the MOE. Discussions on technical aspects of decontamination were also conducted.

In the Act on Special Measures Concerning Radioactive Materials, the authority which implemented the decontamination of the SDA was stipulated as ‘the national government’, but because of the intergovernmental coordination, it was decided that the MOE took the main responsibility to carry out the decontamination activities, with the cooperation of other ministries. It was understood that it would be of key importance to implement such a huge and unforeseen endeavour under a perspective that could be called “a whole-government approach”. This would be particularly important in terms of the technologies to be used, human resources to be made available and also the entrustment of business because the MOE didn’t have experience in running large-scale public projects at that time.

3.5.3. The Special Decontamination Area (SDA), the Difficult-to-Return Zone (DRZ) and The Intensive Contamination Survey Area (ICSA)

The Act on Special Measures defined 2 kinds of areas: the SDA and the ICSA. The SDA almost corresponded to the evacuation areas and decontamination efforts in this area and other remedial actions were to be mainly implemented by the MOE. The ICSA was located in the surroundings of the SDA and, basically, people were not forced to evacuate. The decontamination and other remedial actions in the ICSA were implemented mainly by each municipality, with technical and financial support from the national government through the MOE.

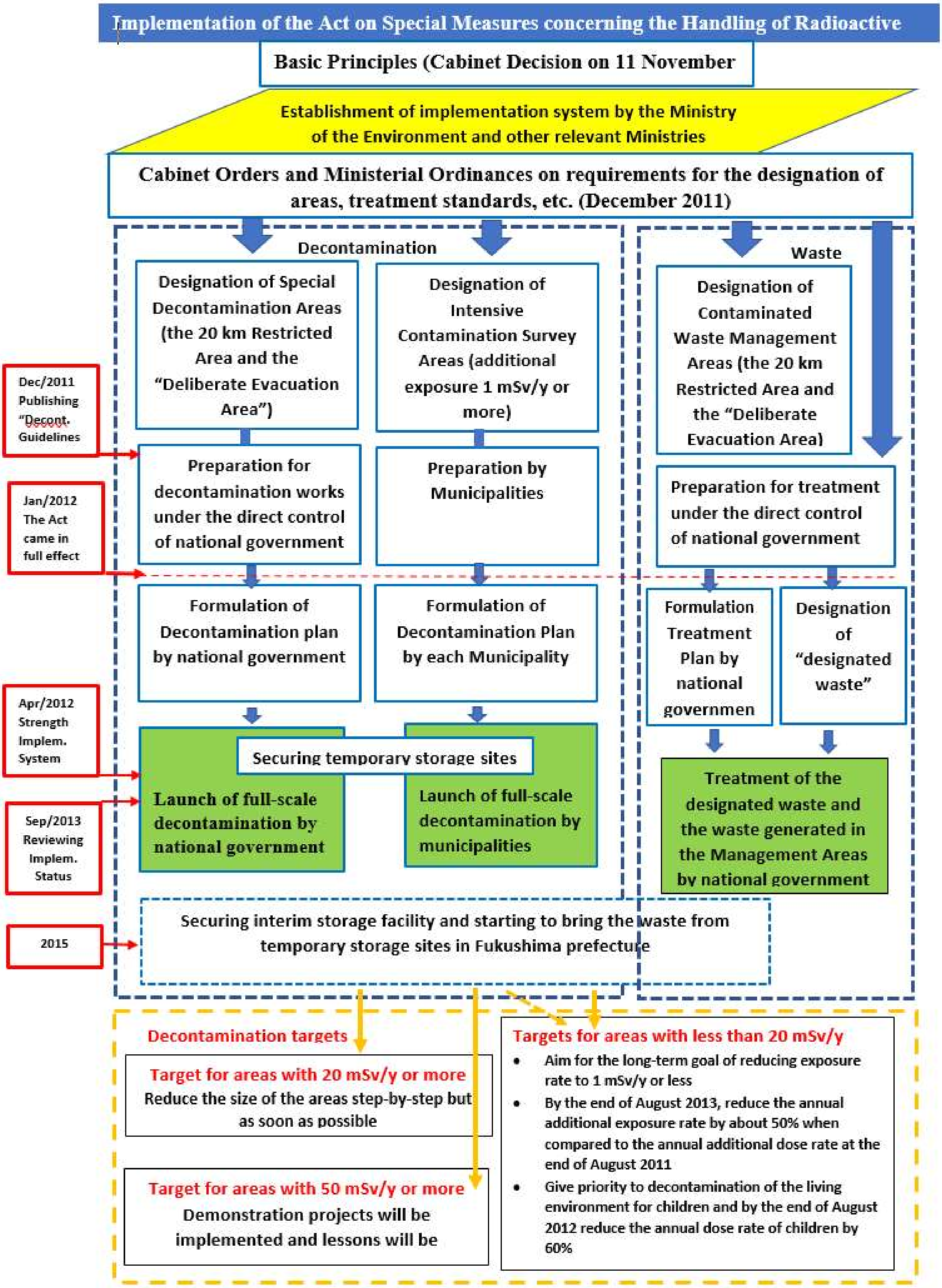


FIG. 1. Outline of the implementation of the Act on Special Measures Concerning Radioactive Materials.

3.5.4. Role sharing between the interested parties

IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [34] establishes that the primary responsibility for the safety must rest with the person or organization responsible for the facilities and activities that gave rise to radiation risks. This principle was incorporated in the Basic Policy that stipulated that TEPCO, the operator of the Fukushima Daiichi NPP, had the primary responsibility for the accident.

However, in Japan, it has been considered that the social responsibility of the Japanese government, which promoted the nuclear policy in the country, should also be taken into account. As a result, the Japanese government became deeply involved with the implementation of the remediation measures. In any case, the magnitude of the accident was too large for only the operator of the NPP to be the sole entity to deal with both the decommissioning and the remediation activities. As a result of the above, the sharing of responsibilities among different actors in the remediation of the Fukushima Prefecture is described below.

As TEPCO has been assigned as the primary responsible party for the environmental contamination, the company became responsible to shoulder the costs of the environmental remediation of the affected areas. TEPCO would also be in charge of addressing the claims regarding all environmental remediation activities based on the Act on Special Measures Concerning Radioactive Materials, including monitoring, surveying, sampling, decontamination, waste management, and other necessary actions for remediation.

In normal disaster response operations in Japan, municipalities are supposed to lead the response to these events under the Disaster Countermeasures Basic Act [33]. However, due to the evacuation of local government in the SDA, the national government was set to lead the remediation operations and recovery activities. For the ICSA, the Basic Policy assigned the local governments as responsible for the remediation works based on the assumption that “the planned decontamination in the community unit is most effectively achieved under the local authorities’ responsibility since administrative functions are in the area, residents are living there, and it is easy grasping circumstances and residents’ needs.”

In practical terms, the Central Government has taken the necessary measures to remediate the radioactively contaminated environment with financial and technical support to Prefectural and Municipal governments. Especially, the MOE, as a leading agency for environmental remediation, has led the remediation in the SDA, provided technical support to, and coordinated the communication and collaboration with prefectural, and municipal governments and other central government agencies (e.g. the Ministry of Economy, Trade and Industry (METI), the Reconstruction Agency (RA), the Ministry of Agriculture, Forestry, and Fisheries (MAFF)). The prefectural governments provided financial, technical, and personnel support to the municipal governments by developing and distributing the guidelines and guidance for environmental remediation and safety measures for remediation workers, coordinating information release and research results regarding remediation and ionizing radiation related issues. The municipal governments have planned and implemented the environmental remediation in the ICSA. The roles of the TEPCO and governments in environmental remediation in the Fukushima Prefecture are summarized in Table 1.

TABLE 1. SUMMARY OF THE TEPCO AND THE GOVERNMENT PRACTICAL ROLES IN REMEDIATION IN THE FUKUSHIMA PREFECTURE

Area	TEPCO	Central Government (MOE)	Fukushima Prefecture	Municipality
SDA	Payment for the expense of remedial actions. Dispatching employees in response to the request).	Funding, remediation plan and implementation, worker training, regulation, policy, information distribution.	Cooperation with the national policy as a liaison between central government and municipalities Information distribution cooperatively with the central government.	Direct communication with evacuees; Support the MOE for remediation plan and implementation, landowner identification and coordination of meetings; remediation information distribution to evacuees, coordination for lifting of evacuation orders and remediation verification committee meetings.
SA	Same as the SDA.	Funding, review and approval of remediation plans, technical support to the Prefecture government (information and experts).	Managing the fund for the remediation, technical supports to municipalities (information and experts), prefecture facility remediation.	Planning and implementation of remediation and information distribution.

3.5.5. Budget and compensation

Other important points of the Act on Special Measures Concerning Radioactive Materials dealt with the financial resources that would be needed to implement the remediation works. In this regard, the Act on Special Measures Concerning Radioactive Materials established that the national government would “take measures to finance the costs required for the promotion of measures to deal with contamination by radioactive materials”, and that “measures related to damage are to be implemented at the expense of the relevant nuclear operator”.

Finally, the Act on Special Measures Concerning Radioactive Materials established that considering the social responsibility of the operator, the national government would implement necessary measures to ensure that the relevant nuclear operator would make timely payments to cover the cost of measures taken by local governments etc. under the Act on Special Measures Concerning Radioactive Materials.

The national government, therefore, has intermittently claimed compensation from TEPCO for expenditures for remediation activities (e.g. decontamination and other remedial actions, storage of waste). It was stipulated in the law, that the TEPCO has to try to respond promptly to the claims made by the government. The amount of budget necessary for the implementation of decontamination needed to be reviewed over time and around Y3 trillion was allocated for the decontamination of both the SDA and the ICSA.

In addition, the Act on Special Measures for the Reconstruction and Restoration of Fukushima [31] was amended in May 2017 to address more promptly the reconstruction and restoration of the Difficult to Return Zone (DRZ). In the wake of this amendment of the Act, the necessary remediation for constructing the Specified Reconstruction and Revitalization Bases (SRRB) was regarded as one of the measures for the rebuilding of the new community and budgeted by the national government.

3.5.6. A review committee of the Act on Special Measures Concerning Radioactive Materials

The Supplementary Provisions of the Act on Special Measures Concerning Radioactive Materials calls for the national government to review the enforcement of the Act, 3 years after the Act was taken into effect. Necessary amendments would need to be incorporated into the Act.

As a result, the MOE established a committee to investigate the progress made with the remediation activities. Five meetings with 11 experts were conducted from March 2015 to September 2015 and a report was published at the end of this period.

The report recognized the progress made as well as setbacks. It was pointed out that some delays were attributed to, for example, the shortage of technical expertise and hands-on experience, education related to ionizing radiation related issues and the time needed for building relationships with the local community.

Additionally, that report raised points to be tackled in the future, such as the acceleration of the decontamination project to meet the goals, with transparency on the progress, the manifestation of the prospect for the construction of the Interim Storage Facility (ISF), the promotion of in-depth explanation and dialogue with interested parties for the treatment of designated waste outside of the Fukushima Prefecture, comprehensive government policy for education about radiation, and cooperation between national and local governments by recognizing more their roles and responsibilities.

3.6. THE ACT ON SPECIAL MEASURES FOR FUKUSHIMA

Taking the unique circumstances and social responsibility of the national government, which promoted the nuclear policy, the Act on the Special Measures for Fukushima was promulgated and taken into effect on March 31, 2012. First, the Act focused on the revitalization of the damaged economy and the creation of new post-disaster businesses in Fukushima. After a couple of amendments to the Act, a new institution for the SRRB was established. After the approval of the plan by the Prime Minister, various kinds of public projects, including decontamination and waste treatment, were implemented under the responsibility of the national government within the base. The progress and other details of the SRRB are touched on in Section 8.

3.7. LESSONS LEARNED RELATED TO THE ADOPTED POLICY AND STRATEGY

Before the accident, institutions were not well prepared to implement measures to deal with radioactive contamination of large areas in Japan. That situation derives from the understanding that a nuclear power station was deemed to be a safe facility and that release of a large amount of radioactive material was not likely.

3.7.1. Institutional arrangement

The large-scale decontamination project in a populated area like Fukushima, aiming to return the evacuees, was the first project of its kind in human history. Therefore, it took time before launching the large-scale decontamination project to reduce the exposure of the population to ionizing radiation.

For the implementation of the decontamination projects, not only the legislation but also other administrative preparation was needed to be put in place (e.g. budget, human resources, responsibility assignment, etc.). It is quite unrealistic to predict all the scenarios that might be associated with a nuclear accident, but it does make sense to be proactive and consider some basic hypothetical situations making the necessary adaptations for country-specific situations.

3.7.2. Role sharing

As mentioned above, the national government took the initiative for the implementation of remediation works in the SDA, considering the social responsibility of promoting the nuclear policy. In the ICSA, each municipality played an important role as an implementor, taking into account their familiarity with the local situation. TEPCO took the primary responsibility to shoulder the costs with the remediation activities as the operator of the facilities that gave rise to the radiation risks.

It was inevitable that some difficulties and constraints were faced at all levels because this was the first experience of this kind for all involved organizations. Each organization had to face issues of different nature e.g. municipalities experienced problems with securing the staff because they did not have abundant human resources. The MOE in its turn was understaffed to undertake such a huge project. Therefore, additional staff were secured from other ministries and included experienced and/or retired professionals from private construction companies and other public authorities.

Regarding the verification of the decontamination projects, that responsibility was placed on an independent regulatory body as clearly specified in the relevant regulations concerning the protection and safety of the public and the environment. Regarding the works conducted by the MOE within the SDA, the Ministry established an investigation committee with the objective of verifying the MOE’s project. The MOE works were also verified in the scope of the municipalities by members of local councils during meetings of the municipal assemblies.

In the municipalities of the ICSA, the verification committees weren’t established as described above, instead, the progress of decontamination was opened to public scrutiny eventually with the support of advisors.

In addition, the Labour Bureau and the National Audit also reviewed project execution, at their discretion, in terms of workers’ safety and correctness of budget execution, respectively.

In case a similar accident happens in the future, it could be beneficial to clarify the entities that have the responsibility for such verifications, not only from the viewpoint of radiological aspects (compliance with established reference levels) but also in terms of proportionality i.e. to ensure that the applied remediation solutions are neither insufficient nor excessive, so as to secure the consistency between the work developed in the different municipalities.

3.7.3. Target

Shortly after the accident, there was an urgent need to establish reference levels that would ensure adequate protection of the public in the affected areas. The dose level of 1 mSv/a (the lower value in the range of 1 to 20 mSv/a) was established as a long-term goal.

This long-term goal was intended to be achieved not only through decontamination works but also by other factors or measures (e.g. natural decay, weathering effects and enforcement of food safety management). However, the understanding of the population in the affected areas was that this goal was meant to be achieved by means of decontamination activities only. As a result, residents repeatedly called for additional decontamination until the air dose rate became lower than the derived reference level (0.23 μSv/h).

The situation made it clear that it is rather urgent that practical guidance in establishing reference levels in the scope of existing exposure situations, particularly after a nuclear accident, is provided. While adopting the lowest value in the range of 1–20 mSv/a might demonstrate to the general public that the government is committed to providing the highest level of protection vis-à-vis the contamination of the environment, achieving that goal may not be practical in the short term. By not achieving this objective, a certain amount of frustration amongst the residents in the affected areas will take place. In addition to this, the decision on the reference level to be adopted needs to consider many other tangible and subjective aspects that need to be clearly and transparently discussed with a wide range of stakeholders so that effective but also sustainable solutions are found and agreed upon.

4. REMEDIATION

4.1. THE INPUTS FROM IAEA–MOE MEETINGS ON REMEDIATION

From the first meeting, it was noted that continued and significant efforts have been put in place by Japan towards the remediation of off-site areas affected by the accident. On that occasion, the experts took note and acknowledged that progress has been achieved through the remediation works undertaken both in the Special Decontamination Area and in the Intensive Contamination Survey Area (ICSA). One of the main challenges faced by the MOE, as a result of the remediation of the affected areas, was the need to manage large amounts of contaminated waste generated during the remediation activities. Techniques and technologies to reduce the volume of generated wastes were being investigated and recycling of these materials was also under consideration. The experts called attention to the usefulness of improving detailed information about decontamination factors achieved for specific techniques applied to specific materials or classes of materials. Also important was obtaining greater detail about the application of a specific method with a view to satisfactorily reproducing the results.

Experts also indicated that additional detailed information to be gathered in ongoing remediation activities that would be invaluable to the international community could be:

- The fraction of a radionuclide that is fixed onto loose particulate and that is subsequently chemically bonded onto structural materials of buildings and roadways;
- Data to distinguish between decontamination factors measured for different types of, concrete types, asphalt, asphalts, composite shingles;
- Established Standard Operating Procedures (SOPS) and associated lessons learned and the effect of evolving worker proficiency in decontamination performance.

The key role of communication of the outcomes of the remediation works to different stakeholders was once again appreciated and valued.

During the second meeting, it was suggested that the MOE could consider developing routine hotspot surveying and rapid remediation action plans in the relevant areas. The possibility that the MOE could gather more information on the methods of dose rate evaluation, to identify whether these methods are equivalent to those documented in the MOE's guidance on decontamination technologies has also been discussed.

Discussions during the third meeting, suggested that the MOE, in cooperation with other relevant organizations in Japan, could consider focusing its efforts to develop remediation plans targeting the DRZ in conjunction with the rebuilding of the infrastructure within the SDA. In that regard, it was seen as important to develop plans for further lowering doses in the SDA following the full-scale decontamination, in order to meet the long-term goal of 1mSv/a. It was agreed that the plans should prioritise the activities and milestones to prepare for repopulation and recovery. Finally, while developing the second decontamination report, the MOE was suggested to reach out to international stakeholders to identify the information that might enhance the completeness of the report. The IAEA team also emphasised the need to consider individual doses, as measured with personal dosimeters, to support remediation decisions. An optimized monitoring programme to follow up on the behaviour of the affected media (soil, vegetation, etc.) could be put in place.

Suggestions were given for the preparation of a comprehensive health monitoring programme to support the returning evacuees. Finally, it was noted that it would be helpful for the MOE to assess the overall practices of stakeholder engagement in the decision-making process and extract important lessons learned. If considered appropriate, the MOE could reorient future practices accordingly, especially during the repopulation of the evacuated areas and continuous remediation to reach the long-term clean-up goal.

In the fourth meeting, the need to continuously assess the effectiveness of the stakeholder communication methods and strategies was stressed. A suggestion was also given to the MOE to continue working on gathering technical data and safety data and specifications for potential soil recycling/reuse with other relevant agencies, and in doing so, gather public input on a variety of policy options for ensuring the protection of public health and the environment.

4.2. ENVIRONMENTAL REMEDIATION APPROACH

According to the Act on Special Measures and Basic Policy the MOE planned and implemented full-scale remediation in the affected area. As mentioned above, the MOE, under the Ministerial Ordinance, designated the contaminated region as two areas: the SDA, the almost same area where the evacuation order was declared and the ICSA where the additional air dose rate is more than 1 mSv/a. The SDA is the area where the central government leads remediation efforts and the ICSA remediation is led by local municipalities with financial and technical support from the central government.

The full-scale remediation plans have been implemented in the SDA and the ICSA from 2012 until 2018. In March 2018, the full-scale remediation was completed for the SDA and the ICSA except for the DRZ (See Section 3). As a result of the full-scale remediation, the air dose rates in both the SDA and the ICSA have been significantly reduced. The dose rate reduction below 20 mSv/a in the SDA is one of the primary requirements to lift the evacuation order and the MOE’s remediation efforts met this requirement leading to the return of the evacuees.

The MOE as a leading agency in collaboration with local municipalities and other central government agencies have made numerous efforts to assure timely, efficient, and transparent remediation work. These efforts included but were not limited to, remediation guideline development, innovative remediation approaches and assessment of waste management methods, coordination of independent advisory committees, supporting technical expertise and experts, stakeholder engagement, risk communication, etc.

Throughout the process of remediation planning, implementation and verification, several challenges have been identified. The information from Japan’s remediation experiences will greatly benefit decision-makers and responders who might need to prepare for wide-area environmental remediation to respond to and recover from an unlikely nuclear power plant incident. This section focuses on these remediation challenges.

4.2.1. Environmental remediation goal

The Japanese government conservatively adopted as a reference level for the remediation activities the lower value in the range of 1–20 mSv/a as applied in existing exposure situations [32]. As already mentioned, an intermediate reference level, after proper review, could be possibly adapted in line with the gradual improvement of the situation. However, as a long-term goal, efforts should be aimed at achieving the level of 1 mSv/a.

The Japanese government decided to conduct remediation to help reduce radiation doses faster than natural attenuation. Remediation activities included variables such as various forms of decontamination, shielding and soil ploughing. The idea is to have radiation doses reduced so that the return of residents of contaminated areas could be enabled as well as the restoration of livelihoods.

4.2.2. Preparation for remediation

The Japanese government took several steps to identify the most applicable remediation methods. The Clean-up Subcommittee of the Atomic Energy Society of Japan (AESJ) disseminated the Japanese translation of datasheets of the European Approach to Nuclear and Radiological Emergency (EURANOS) Remediation Technology in August 2011 and the AESJ published the remediation technology catalogue based on the EURANOS datasheet by incorporating remarks when applied in Japan in October 2011. The catalogue includes remediation technologies for common surfaces in the contaminated area such as roofs, house walls, house gardens, paddy fields, dry farmland, fruit gardens, pasture, forests, aquatic fields, housewares, community facilities, etc.

4.2.2.1.Identification of Environmental Remediation Approaches

The MOE directed the JAEA to initiate the review of candidate remediation methods from national and international sources in order to identify the candidate methods with that could comply with the established criteria of applicability (radioisotope, surface and media) and availability. The candidate methods were evaluated by contractors from 2011 to 2015. The evaluated methods included (ultra) high-pressure water washing, surface removal of roads and concrete, classification of soil, top-soil removal, precipitation and classification of bottom sediments in ponds, high-pressure water washing on bark, shot blasting of asphalt, volume reduction and/or incineration, caesium separation from the soil etc. [34]. The selected methods were then further evaluated in actual contamination conditions and scale, to confirm the remediation method effectiveness. The JAEA was commissioned to implement the Decontamination Model Projects to identify effective remediation measures and approaches to ensure the radiation protection of workers. The projects focused on the collection of key operational parameters of individual remediation technologies such as effectiveness, waste type and amount, cost, time, labour, difficulty and limitations, safety, resources, monitoring to identify hotspots, environmental impact, prevention of recontamination, project management, waste reduction, remediation worker safety, and stakeholder concerns. The Decontamination Model Projects were conducted in three areas that had additional radiation dose rates between 1−20 mSv/a. The results of the Decontamination Model Projects are published in Refs [35-37]. The tests were conducted by the public work contractors (mostly general construction companies) because of their availability and possession of the necessary skills, equipment and labour to remediate large, contaminated areas. Construction companies had not had previous experience in the remediation of radioactively contaminated sites. The participating companies accumulated knowledge and experience through the testbeds. The construction companies further developed their expertise in environmental remediation and have served as the main performers of remediation in the SDA and the ICSA.

The MOE developed the Decontamination Guideline in 2011 to support municipal governments for whole area implementation in the ICSA and to guide remediation in the SDA for remediation contractors. This guideline document included technical information for contamination surveys, decontamination, and waste management targeting ^{134}Cs and ^{137}Cs. The information in the guidelines was the summary of the results and experiences from the preliminary remediation efforts led by several local municipalities soon after the incident, technology catalogue and the Demonstration Model Project. The approaches in the guideline document have been continuously revised and improved by applying the lessons learned from the ICSA and the SDA remediation experiences. The Fukushima Prefecture and the MOE continued to search for available technologies for remediation with better efficiency and less waste volume generation throughout the remediation works. The remediation technology identification and improvement activities of the central, prefecture, and local governments are summarized in Table 2.

TABLE 2. JAPANESE AGENCIES EFFORTS TO IDENTIFY AND IMPROVE REMEDIATION TECHNOLOGIES

Agencies	Activities
Date and Koriyama City	Preliminary remediation on local facilities in April 2011.
Japan Atomic Energy Society	Comprehensive Handbook for Residential Area Management' (in Japanese) translated from the 'EURANOS Data Sheet' that contains 59 remediation technologies for the residential environment on 12 August 2011 [38]. Technological catalogue (in Japanese) on houses, farmland, forests, aquatic environments, public facilities, industrial buildings, living areas and others was issued.
JAEA	Selection of specific methods and development of Decontamination Catalog with 64 methods (27 non-residential and 20 unique to Japan) in October 2011. Conducted Decontamination Model Projects in the areas with an additional dose rate of 1–20 mSv/a within Fukushima Prefecture to collect operational information of remediation methods. Conducted Decontamination Pilot Project within the evacuation zone to examine the applicability of remediation techniques on a larger scale.
Cabinet Office	Decontamination Technical Catalog of 23 methods from JAEA's remediation Catalog in November 2011.
MOE	Compiled all applicable and effective methods tested to support municipalities in the ICSA for remediation (survey, decontamination, waste management) and published Decontamination Guideline in December 2011 (Rev. 2013, supplements 2013, 2014, 2016) [39]. Conducted Decontamination Technique Demonstration Projects in 2011–2015 to assess 67 methods for their efficiency and effectiveness via field evaluation focused on new remediation technologies; applicability, effectiveness, cost, time, safety. Published Guidelines on Handling Local Areas Contaminated by Radioactive Materials in March 2012. A published collection of good practices in remediation in May 2013 by compiling knowledge and experiences and lessons learned from remediation performers from remediation sites. As part of yearly Demonstration projects, conducted Decontamination and Volume Reduction Technology Demonstration Project in 2015. Conducted Volume Reduction of Decontaminated Soil Technology Demonstration Project since 2016.
MAFF	Farmland specific method evaluation; survey and design, work process (each type of work, method, and process), quantification (productivity), reference materials; Publication of appropriate methods of remediation of farmland in September 2011 and Technical Document for Decontamination of Farmland in February 2013. Published technical guidelines on removal and control of scattering of radioactive materials in the forest in April 2012 to help guide how to remove sedimentary organic matter and improve understanding of characteristics of forest contamination.
Fukushima Prefecture	Conducted Full-Scale Decontamination Model Projects to assess 49 methods for their efficiency and effectiveness focused on radiation dose reduction in living area, waste amount and type, safety, public water impact; Produced Technical Guidelines on Decontamination Operations (revised in February 2014) and Handbook for Full-Scale Decontamination (March 2012).

4.2.2.2.Remediation Contractors and Workers

Construction companies for public works ('contractors') were the main remediation business operators in Japan. This was because most of the remediation activities resemble ordinary public work projects. The MOE used the existing ordering framework for ordinary public projects with supplementary additions of matters specific to radioactive material handling and remediation work. Relevant public notices were issued for procurement based on the specifications and remediation contractors. Common and special remediation specifications can be found in the previous MOE report [40].

Remediation costs in the SDA were estimated using the Provisional Estimation Standards (PES) which specified materials and equipment, workload, unit prices of machinery, workforces, expenses, etc. required for implementing the remediation works [41]. The PES was developed based on the results for JAEA's Decontamination Model Projects in 2011 fiscal year, and the results of independent remediation projects performed by municipalities in the Fukushima Prefecture. The information in the PES had been further revised to reflect the actual site situations (e.g. modification of remediation methods, new methods, etc.) as remediation progressed. The cost of remediation work had to consider various factors such as the size of the site, surfaces of structures (e.g. roofs, walls, windows, etc.), types of land use (e.g. gardens with or without trees and other types of vegetation); remediation methods, needs of special equipment (e.g. boom lift, bucket crane, work vehicles, scaffolds, etc.), surrounding forests, route to transport removed soil, etc. In the ICSA, the 'Fukushima Prefecture Decontamination Provisional Quantification Standards' was used for remediation cost estimation [41]. Each municipality generally followed the Fukushima Prefecture's common specifications and quantification standards when ordering work. For matters not specified therein, they responded by using the common specifications and quantification standards issued by the MOE.

When each worker joined the remediation project for the first time, they had to take mandatory training for remediation work procedures, basic regulations, general field safety and health, radiation safety including the use of a whole-body counter, and communication with the residents. These training courses took place at the beginning of the work and were periodically offered to remediation workers. Each contracting company had the flexibility to implement the mandatory training adapted to their needs in a way to improve their effectiveness. The companies used various resources including traditional classroom training, interactive sections to exchange their opinions and good examples, educational movies on YouTube produced by the Ministry of Health, Labor and Welfare (MHLW), and workshops arranged by the Fukushima Prefectural Government and the MOE for the workers and work leaders.

The exposure of workers was managed by each contracting company following the relevant legislation. Individual workers at remediation sites were monitored for their daily exposure, before and after their work, by means of personal dosimeters. To obtain information about possible internal contamination they were screened by means of whole-body counters. The data were uploaded to the individual contractor company's database. Remediation workers, however, were often moved from one contracting company to another depending on the situation: some of them moved to where better working conditions were offered, and others just moved according to the transition of the labour demand of the remediation projects or other relevant reconstruction projects. In November 2013, a management system was implemented to track the radiation dose of individual remediation workers regardless of their company affiliation, and each contracting company regularly submitted the information on the exposure of the workers to the authority and the information has been managed in an integrated manner.

4.2.3. Implementation of remediation

The MOE published the Policy for Decontamination in Special Decontamination Areas in January 2012 [41]. This remediation roadmap addressed the series of steps consisting of Decontamination Model Projects, preliminary remediation, full-scale remediation, and detailed remediation implementation steps for each municipality in the SDA. In November 2011, the MOE conducted monitoring on residential areas to characterize the SDA prior to remediation. The Japan Self Defence Forces in January 2012 supported the MOE to remediate the critical facilities to use as a base camp for full-scale remediation in the SDA including municipal offices, community centres, access roads, and water infrastructure. The MOE conducted preliminary remediation in 10 municipalities in the SDA until January 2014 and the Decontamination Model Demonstration Project inside the Restricted Areas of the Joban Expressway in 2012 [31, 37].

4.2.3.1.Special Decontamination Area

Following the preliminary remediation, the MOE developed the remediation implementation plan in the SDA by communicating with the heads of the municipalities and the governor of the prefectures. The plans were then further revised after meetings with the municipalities and residents. The meetings discussed mostly radiation and contaminations levels, remediation methods and effects. In parallel to environmental remediation, infrastructures (e.g. governmental facilities, health facilities, fire stations, utilities, etc.) were developed to help accelerate the return of the evacuees. The full-scale remediation plan in the SDA started with the areas that had lower radiation doses to help as many evacuees as possible to return to their homes as soon as possible.

Individual sites were remediated by following the six steps shown in Fig. 2. The landowner of the target remediation site was identified and briefed about details regarding the field survey to get an access agreement. Site radiation monitoring and surveys were conducted and, at the same time, damaged buildings and structures were surveyed and photographed. The contractor planned the site remediation including a selection of remediation methods. The plan was explained to the landowner so that permission for the implementation of the activities could be granted. If no landowner responded for more than 3 months, it was considered that consent was granted. Remediation was implemented with the option chosen by the landowner. Post remediation survey was conducted and the results on dose reduction were reported to the landowners. Following the completion of the remediation, site radiation monitoring was continued to check the dose rate for residents upon their return.

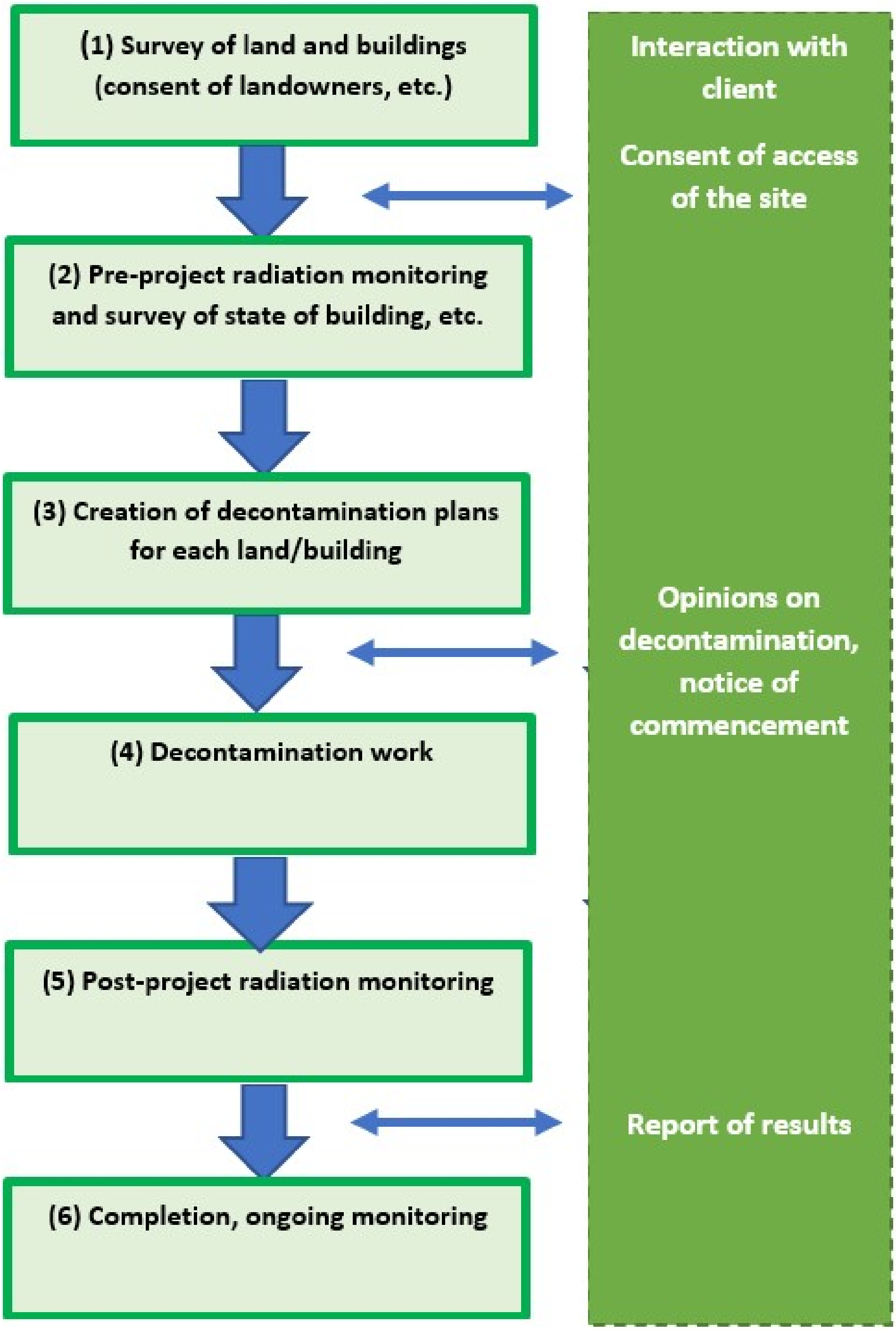


FIG. 2. Site remediation steps (reproduced from [31] with permission).

4.2.3.2. Intensive Contamination Survey Area

In municipalities designated as part of the ICSA, each municipality investigated the contamination of the environment with radioactive materials and made the decision on remediation.

The municipal mayor developed the remediation plan by specifying the area where remediation was needed, remediation methods, remediation contractors, strategy, execution timeline, etc. The MOE reviewed the municipality's remediation plan for technical feasibility and effectiveness. Remediation plans were developed and implemented in 93 out of 104 municipalities in the ICSA. In some municipalities, the radiation dose level was already below 0.23 μSv.h^{-1} (the criterion for the ICSA) due to natural decay and weathering.

Remediation planning in the ICSA considered input from numerous stakeholders including local governments, Parent-Teacher Associations, regional city council members, heads of neighbourhood associations, etc. Planning included remediation sequence (strategy), confirmation of rainwater and surface water flow, Temporary Storage Sites, etc. Individual municipal remediation plans were varied for implementation time and strategies depending on the situation and condition of municipalities. However, remediation methods were within the technical approaches in the MOE's Decontamination Guidelines.

Individual municipalities implemented the remediation plan. Municipalities held community meetings to brief the remediation plan and obtain consent for remediation and TSSs and ordered remediation work to hire remediation contractors. Radiation protection experts were appointed as advisors in some municipalities. In each municipality, new divisions and branches were created to carry out the remediation work. Many municipalities in the Fukushima Prefecture also suffered from the earthquake and tsunami. So new organizations were responsible for disaster recovery and needed more workforce. For this reason, some municipalities were assisted by other Prefectures or employed temporary staff.

4.2.3.3. Remediation workflow and methods

Japanese government prioritized environmental remediation implementation as follows: children's areas (schools, parks, community facilities), residential areas, public facilities, other living areas including roads, farmlands and forests. Remediation methods in the ICSA were selected from the MOE's Decontamination Guidelines. These guidelines were developed mainly to help municipalities in the ICSA and were also applicable to remediation activities in the SDA. The guidelines included practical information to implement numerous remediation methods for various surfaces and media. The information included procedures site preparation, site monitoring and survey, material and equipment requirements, handling, cleaning, procedures for site characterization, remediation application steps, verification, waste treatment, packaging, transportation, storage, degree of completion etc.

In the SDA, the MOE published the remediation methods - Common Specifications for Decontamination and Other Work that were applicable for high radiation dose areas [40]. This document has been updated by the MOE as experience and lessons were gained through remediation work. In April 2017, the tenth edition of Common Specifications for Decontamination and Other Work was released. Some methods in this collection were not listed in Decontamination Guidelines. In this document, the remediation methods were categorized first by land-use (e.g. residential areas, schools, park, road, etc.), then each land use was further categorized as compartments of land (e.g. roof, wall, garden, etc.), each compartment was further separated by material types (e.g. concrete and non-concrete material for roof, mud and other earth material for wall, etc.). An example is shown in Table 3.

Remediation methods in the MOE's Common Specifications for Decontamination and Other Work were not practical to apply in the ICSA because of their aggressive removal approaches targeting high dose area remediation. Each municipality generally followed the Prefecture's common specifications and quantification standards when ordering work, and for matters not specified therein, they responded by using common specifications and quantification standards issued by the MOE.

Below is the summary of site remediation workflow and detailed information available in the MOE’s Decontamination Guidelines [35].

- Preparation: preparing the equipment and materials required for the work, safety measures for workers, and safety measures for the general public (access control);
- Site characterization: site contamination levels (air dose rate) were measured at multiple locations within a site prior to remediation. The recommended instrument types were NaI or CsI scintillation survey meters and Geiger–Müller survey meters;
- Remediation method selection and application: remediation methods were selected and applied based on the following principles:

  (a) Remediation work was conducted from the top (high location) to bottom (low location) or from upstream to downstream to prevent any potential recontamination of remediated or clean areas.
  (b) During site characterization, hot spots were first identified and targeted for remediation. The hot spots were often found on the rain flow pathways such as street drains, rain downspouts, gutter, drainage points under eaves, tree bases, etc. Cracks and gaps on roads and interlocking pavement were often found to be hot spots due to contaminated water transportation and accumulation. Hot spots were frequently generated there caused by rain dripping from roofs.
  (c) The preferred remediation methods were those with low waste volume generation. When remediation wastes were generated, incineration wastes were separated from other waste types to minimize the waste volume from remediation. Remediation methods using water were avoided if alternate methods were available. This was to prevent potential contamination spread and to reduce radioactive wastewater.
- Post-work measures: waste packaging, transporting, and storage, wastewater treatment, and equipment cleaning.
- Post-remediation measurements: remediation effectiveness was measured after completion of the remediation work. The air dose rates were measured at multiple locations within a site. Measurements were carried out at the same locations as the pre-remediation measurements and under the same conditions to the extent possible.
- Record keeping: all measurements made during the site remediation were recorded. The recorded data included remediation site location, date, contractor and worker information, surface and objects remediated, remediation methods, total remediated area, waste weight, used equipment, and the method of disposal after use.

TABLE 3. MAIN REMEDIATION METHODS (reproduced from [35] with permission)

Classification	Subject to decontamination		Main Decontamination Method (Choose the appropriate method)
Residential area, school, park, large facilities	Roof. rooftop		Removal of sediment/wiping, brush wash, high-pressure water wash.
	Exterior wall. moat		Wiping, brush wash, high-pressure water wash.
	Rain gutter		Removal of sediment, wiping, high-pressure washing.
	Yards grounds	Unpaved surfaces	Removal of sediment, weeding, lawn mowing, deep cutting of the grass, stripping of grass, laying of new turf. Gravel and crushed stones cleaning by high-pressure water, removal and covering of gravels and crushed stones removal of topsoil at drainage points under eaves, removal of topsoil near the root of tress, scraping surface soil, coating, inversion tillage. Trimming of yard trees – planting, logging and stumping of obstacle trees, restoration of yard soil.
		Paved surfaces	Removal of sediment, brush washing, high-pressure washing, scraping, blasting, extra high-pressure water washing
	Playground equipment		Wiping, cleaning and scraping.
Road, slope	Unpaved roads		Weeding, removal of sediment, scraping of topsoil, covering, inversion tillage, a high-pressure wash of gravel and crushed stone, gravel. crushed stone removal. Coating.
	Guardrails		Brush cleaning, high-pressure water cleaning, wiping.
	Roadside gutters		Removal of bottom sediment.
	Footbridges		Removal of sediment, high-pressure water cleaning, wiping, brush cleaning.
	Roadside trees		Removal of sediment, high-pressure water cleaning, wiping, brush cleaning.
	Slopes		Removal of grass. fallen leaves. Sediment.
Farmland	Paddy fields, fields		Weeding, scraping of topsoil, mixing with water and removal of soil, inversion tillage, deep ploughing, deep tillage, willow tree cutting down, chipping, root removal, pulling out, clear-cutting of bamboo, logging of obstacle trees. root cutting, additional soil, cutting and removal of shrubs, soil restoration, fertilization
	Pastures		Weeding, scraping of topsoil, deep ploughing, deep tillage.
	Waterways		Removal of bottom sediment
	Levees		Removal of sediment, weeding, scraping of topsoil.
Grassland strips			Cutting of shrubs, thinning of bamboo.
			Coniferous trees, cutting and removal of undergrowth and shrubs, removal of organic residue sediment.

Due to unknown situations at the NPP site, as caused by the earthquake, the MOE supervisory personnel and contractors proceeded through trial and error. Before commencing the individual site remediation, test work was conducted to choose the most effective methods from a candidates' list for particular target objects and/or locations. These test works were identified by the Investigative Committee on Remediation organized by the MOE. When no further significant reductions in radiation levels were observed with repeated application, the contractors reported the results to the MOE Committee and followed the directions. The results of test work helped optimize the remediation approaches tailored to the specific site. The example optimization included the number of wiping actions, the depth and speed of deep ploughing work, the water jet pressure and moving speed of high-pressure road surface cleaners, etc.

When remediation methods were tested at the site, methods that removed less material were tried first and when these were not effective then methods involving more material removal were applied. For example, roadway remediation can be tested from less intrusive to more intrusive methods in the following order: removal of deposits, wiping, brushing, pressure washing, removal and replacing. Remediation methods with more surface material removal generally provide a higher decontamination factor, but these methods also generate greater amounts of waste, require more time and give rise to increase costs. Table 4 lists some examples of remediation methods with varying degrees of removal for three target surfaces and media. The third IAEA–MOE meeting commended the MOE for its continued efforts and suggested sharing its achievements and lessons learned obtained from the 'full scale' decontamination efforts.

TABLE 4. EXAMPLE REMEDIATION METHODS WITH VARIED SURFACE INTRUSIVENESS

The extent of removal of contamination from a given surface	Roof	Wall	Lawn
Low	Removal of deposits	Removal of deposits	Removal of deposits.
⇩	Wiping	Wiping	Weeding, lawn mowing.
High	Brushing	Brushing	Deep cutting of turf. Grass stripping.

Approximately 570 000 structures in the ICSA and 22 000 residential lots in the SDA required remediation. In buildings such as houses and large facilities, remediation was conducted from top to bottom in the following order to prevent the spread of contamination. This workflow or residential area is summarized in Fig. 3.

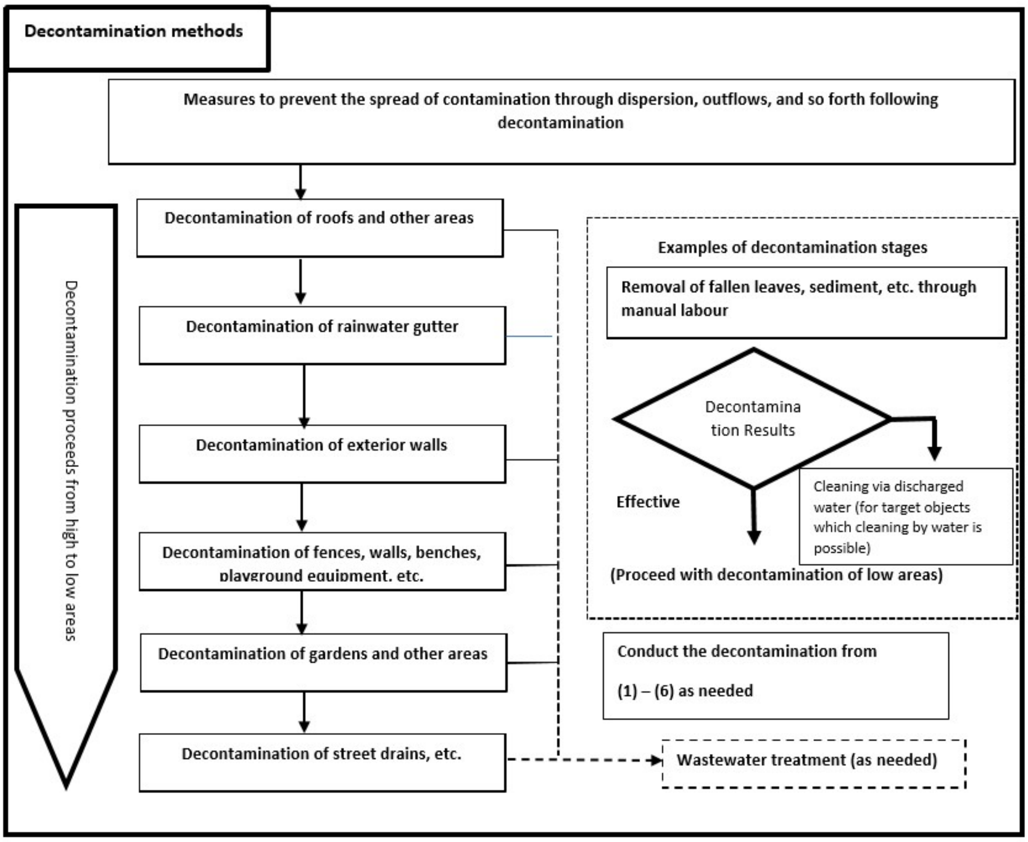


FIG. 3. The basic flow for the remediation of buildings and other structures (reproduced from [35] with permission).

Each step of the remediation involved multiple methods to achieve the final goal. For example, a roof was first remediated by removing surface debris such as fallen leaves, dirt, and moss via handpicking and wiping. When the reduction in radiation levels was not enough from debris removal, then the roof was cleaned using a high-pressure washer or brushing. When the cleaning did not achieve the necessary reduction, then roof materials were removed. Exterior walls were wiped off, brushed, and washed with high-pressure water. Then, contaminated soils in the garden were removed and the ground was covered with fresh soil or gravel. This stepwise approach was applied to every remediation step. The selection of remediation methods in each step was determined based on surface types and contamination level with preliminary tests prior to full application. Figures 4 (A) and (B) show two remediation methods applied on various objects in residential areas and large-scale facilities.

(A). Removal of sediments *(B).* Wiping of roof

FIG.4 . Example of two different decontamination methods in a residential area.

As part of the remediation of a residential area, forests near the residential structures were remediated to effectively reduce the radiation dose in the living area. Total forest sizes that required remediation were 5,800 ha in the SDA and 4,800 ha in the ICSA. The Decontamination Guidelines stated that organic substances such as fallen leaves should be removed within an effective range of 20 m from the edge of the forest to reduce the radiation dose in the residential area bordering the forests. Figure 5 shows the basic flow of remediation of forests near residential areas. Before investing substantial time and efforts in remediating forest areas, a safety assessment is carried out to indicate if such action would lead to a reduction of doses for the public. If not, efforts need to be concentrated in areas that would bring greater benefits. This safety assessment is made by making use of the results of the demonstration tests.

On 26 September 2012, the MOE issued arrangements on forest decontamination methods and stipulated that decontamination was to be prioritized. Further instructions were announced on 21 December 2015, based on the findings from previous works. Forest decontamination was then classified into three categories based on the following prioritization:

- Area A: Nearby forests such as dwellings;
- Area B: Forests that users and workers enter on a daily basis;
- Area C: Forests other than areas A and B.

For area A, in the range of about 20 m from the forest edge, organic substances were to be removed, and for forests that delivered high doses to the surrounding settlements, countermeasures were implemented separately by extending the works beyond 20 meters. For area B, weeding, removal of organic substances, etc. were carried out based on the examination of the effective and rational decontamination method after evaluating actual conditions of the use of the place where people would enter daily. For area C, additional data and information are collected to understand how the radioactive materials migrate. Conditions of the outflow and migration of radioactive materials from the forest to the living area have been evaluated to ensure the safety of residents. In addition, demonstration projects were implemented by the MOE to promote appropriate forest management and to evaluate radioactive caesium migration to other areas.

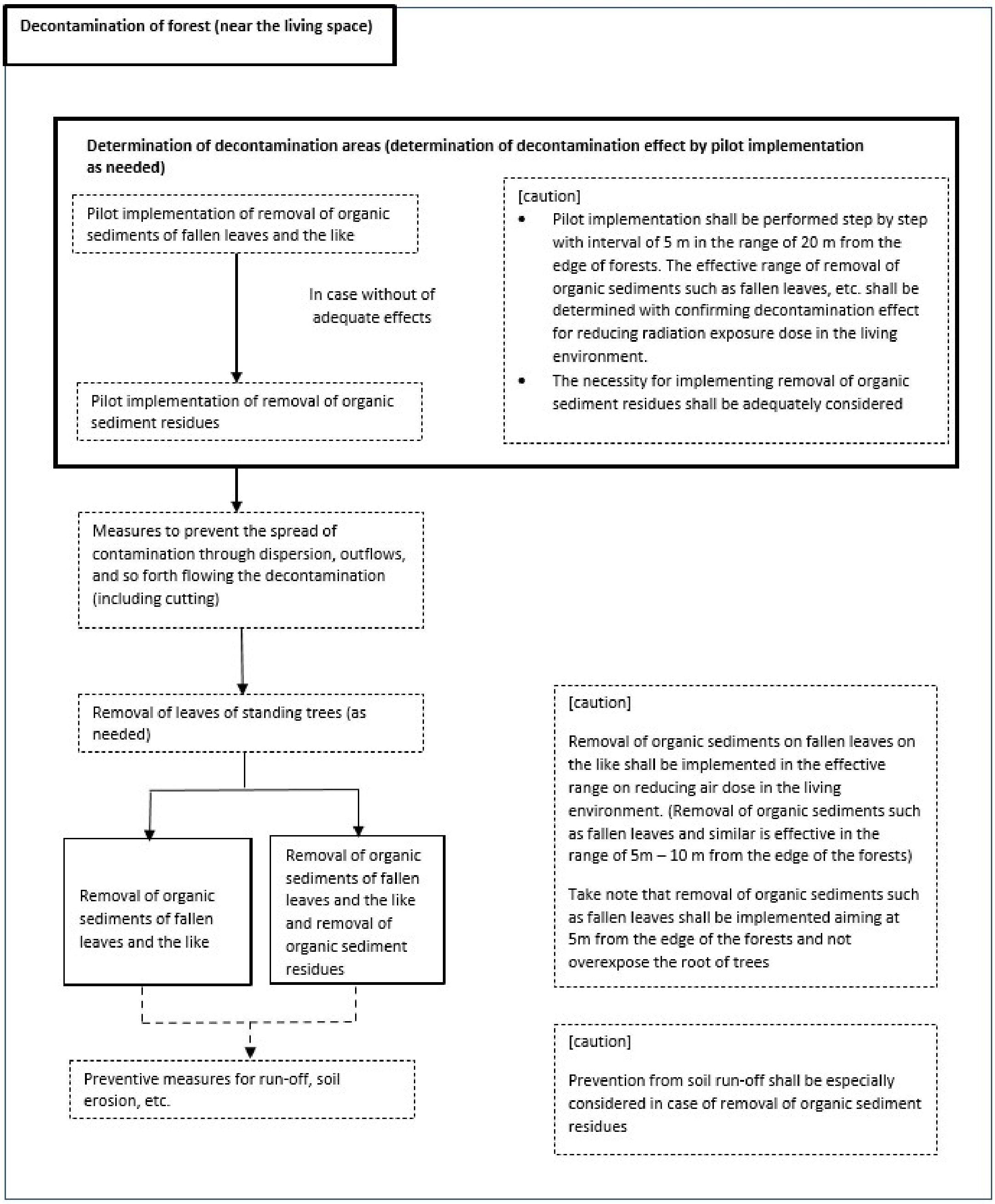


FIG.5. The basic flow of remediation of forests near living areas (reproduced from [35] with permission).

The most effective forest remediation methods were the removal of organic matter such as fallen leaves and removal of branches and leaves 5–10m from the edge of forests. These remediation methods were incrementally implemented by 5m from the edge of forests. The critical consideration of forest remediation was erosion prevention when organic sediment residues were removed. Post remediation work was sometimes conducted to prevent soil erosion by setting sandbags and fences at appropriate locations such as the very edges of the peripheral areas around forests. A significant length of roads was remediated in the SDA and the ICSA (1500 ha and about 24 240 km, respectively as of March 2018). The basic workflow of road remediation is summarized in Fig. 6.

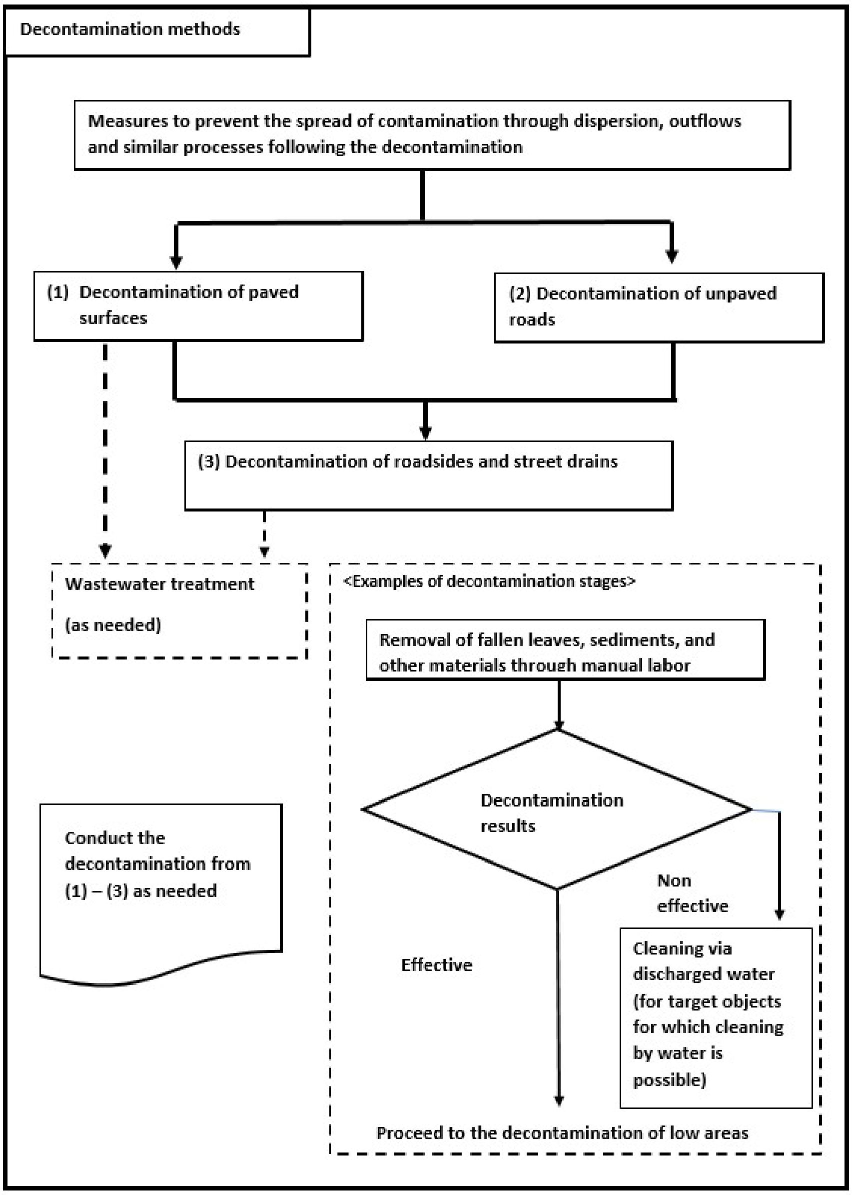


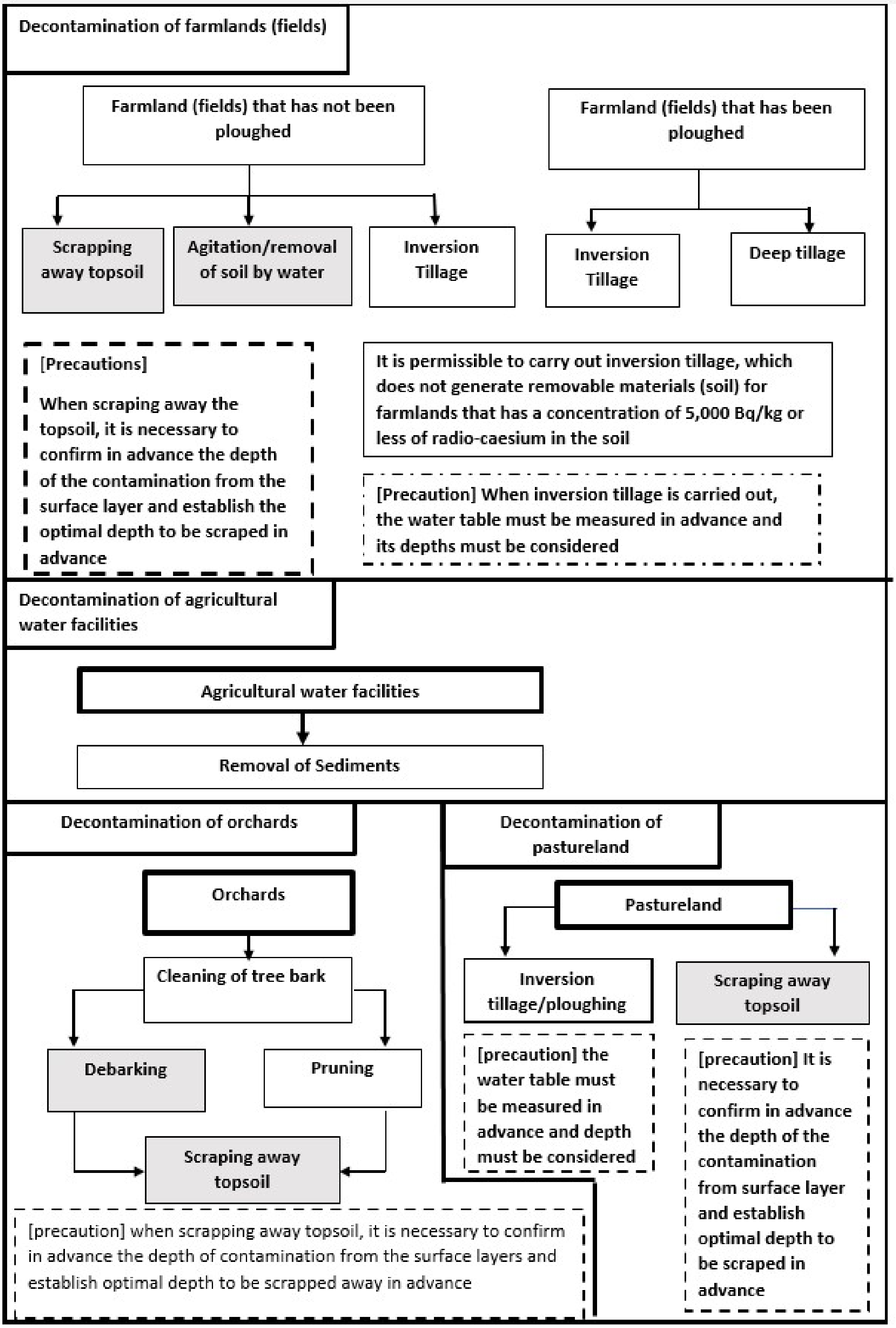
FIG. 6. The basic flow for the remediation and other measures for roads (reproduced from [35] with permission).

The remediation of roads involved dealing with the road itself as well as street drain and roadsides. Different remediation methods were applied for paved and unpaved roads. For paved roads, three levels of remediation methods were used i.e., sediment removal (hand picking, shovel, or road sweeper, etc.), cleaning (brush cleaning or high-pressure washer cleaning), scraping away (surface blasting, ultra-high pressure washer cleaning, surface cutter). For unpaved roads, the initial remediation was the removal of sediments. Soil roads were remediated by deep ploughing, topsoil removal or surface soil covering. If the road was made of gravel and crushed stone, the remediation was conducted using high-pressure washer cleaning of gravel and stones or replacement of gravel and crushed stones. For sloped road remediation, first weeds were removed and if the radiation level persisted, then topsoil was removed. Roadsides and street drains were remediated by sediment removal, brush cleaning, or high-pressure washer cleaning. Road remediation methods needed careful measures to contain the contaminated particles or water droplets to prevent spread to other surfaces.

The agricultural areas remediated in the SDA and the ICSA were approximately 8500 ha and 32 600 ha, respectively. Various remediation measures were used to ensure the safety of agricultural products. The remediation approaches were determined based on the caesium activity concentration level in soil, types of products, and site conditions (whether ploughed or not, presence of vegetation, etc.).

Figure 7 shows the remediation workflow on farmland. In farmlands, especially rice fields, remediation approaches varied depending on whether the land was cultivated after the accident or not. In such cases, it was not effective to scrape off the topsoil because caesium originally deposited on the topsoil layer was vertically mixed during the cultivation process. For the farmlands ploughed after contamination (less than 5000 Bq.kg^{-1}), inversion tillage, deep tillage, and sludge removal in waterways were used as remediation methods. For the soil with contamination levels exceeding 5000 Bq.kg^{-1}, a layer of 3−5cm from the surface was removed. Deeper removal, over 5 cm from the surface, was implemented for soils with higher activity concentrations. In such cases, soil solidifying agents were identified as an option to prevent dust scattering, as necessary, to protect decontamination workers from radiation exposure.

For orchards, deep tillage or inversion tillage was not used due to the potential damage of the tree roots. The applied remediation methods were debarking using a dedicated chipping tool to take off tree bark that had grown old, and tree bark cleaning for tree species for which debarking was not applicable, such as peach trees and cherry trees. Pressure washer use for cleaning bark or debarking caused dispersion of wastewater, so these methods were not used during the growing season and performed during the dormant season. Regarding remediation of fruit trees, the surfaces on which the bark was not removed (such as young peach, yellow peach, plum, apple, pear and others) remediation was performed using high-pressure washing equipment. This treatment removed approximately 55% of caesium from tree surfaces. For the trees with bark that could be removed (such as grape, Japanese persimmon, apple and pear), the radiation levels were reduced by 80−90% by scraping off the surface or removing the bark.



[Precautions]

When scraping away the topsoil, it is necessary to confirm in advance the depth of the contamination from the surface layer and establish the optimal depth to be scraped in advance

It is permissible to carry out inversion tillage, which does not generate removable materials (soil) for farmlands that has a concentration of 5,000 Bq/kg or less of radio-caesium in the soil

[Precaution] When inversion tillage is carried out, the water table must be measured in advance and its depths must be considered

[precaution] when scrapping away topsoil, it is necessary to confirm in advance the depth of contamination from the surface layers and establish optimal depth to be scrapped away in advance

[precaution] the water table must be measured in advance and depth must be considered

[precaution] It is necessary to confirm in advance the depth of the contamination from surface layer and establish optimal depth to be scraped in advance

FIG.7. The basic flow of remediation of Farmland (reproduced from [35] with permission).

4.3. RESULTS OF REMEDIATION

The full-scale remediation in the SDA (except the DRZ) and the ICSA was performed from 2012 until 2018. This remediation project cost approximately Japanese Y2.9 trillion[5] (Y1.5 trillion and Y1.4 trillion for the SDA and the ICSA, respectively) and generated 17 million m^3 (9.1 million m^3 and 7.9 million m^3 from the SDA and the ICSA, respectively) of radioactive remediation waste. The management of remediation waste is discussed in Section 5. The remediation also required enormous labour efforts and the cumulative worker efforts were approximately 13.7 million and 18.4 million man-days in the SDA and the ICSA, respectively.

4.3.1. Results of the Special Decontamination Area (SDA) remediation

The average air dose rate from remediation in the SDA are shown in Fig. 8. The dose rate was measured 1 m above the ground surface. The average air dose rate in the SDA was reduced from 1.31 $\mu Sv.h^{-1}$ to 0.62 $\mu Sv.h^{-1}$ right after remediation and to 0.44 $\mu Sv.h^{-1}$ after several months of remediation. The average air dose rate reduction was 53% and 67% right after remediation and several months after remediation, respectively. The air dose rate right after remediation was reduced by 40–60% depending on the land use types (residential area, farmland, and road) compared to the pre-remediation level. After several months of remediation, the air dose rate reduction was even larger (about 60-75%). The air dose rate in a forest near a residential area showed a 30% reduction right after remediation and 55% reduction several months later. The tendency in air dose rate results was that remediation of high radiation areas showed a greater reduction and the air dose rate reduction tended to increase as the amount of removed soil increased.

The data (more than 260 000 locations) in the residential areas included houses, schools, parks, cemeteries, and large facilities and more than 96% of the residential locations had an air dose rate of less than 3.8 $\mu Sv.h^{-1}$. The average air dose rate was reduced from 1.39 μSv/h to 0.56 μSv/h after remediation. The average reduction in residential areas was about 60% right after remediation.

For the remediation of farmland, air dose rates were measured in about 120 000 locations including paddy fields, orchards, and meadows. About 98% of the farmland locations had air dose rates less than 3.8 $\mu Sv.h^{-1}$. The average air dose rate was reduced from 1.45 μSv/h to 0.59 μSv/h just after remediation. The average reduction in dose rates in farmland areas was about 59% right after remediation.

For forests near residential areas, air dose rates were measured in about 94 000 locations including slope, grassland and lawns. In about 98% of forest locations air dose rates were lower than 3.8 $\mu Sv.h^{-1}$. The average air dose rate was reduced from 1.59 $\mu Sv.h^{-1}$ to 1.11 $\mu Sv.h^{-1}$ right after remediation which is equivalent to an average reduction of about 30%.

For road remediation, air dose rates were measured in about 87 000 locations including paved roads, gravel or crushed stone roads, and dirt roads. About 98% of road locations had an air dose rate lower than 3.8 $\mu Sv.h^{-1}$. On average, the air dose rate was reduced from 1.21 $\mu Sv.h^{-1}$ to 0.67 $\mu Sv.h^{-1}$ after remediation. The average reduction rate of the road was about 44% right after remediation.

The estimated air dose rate with remediation in the SDA was reduced by approximately 59% compared to the air dose rate without remediation. It has been estimated that approximately 18 years would be needed to have air dose rates falling to 0.32 $\mu Sv.h^{-1}$ if remediation were not conducted. This

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[5] Approximately US $26.5 billion

estimation shows that remediation accelerated the dose reduction compared to just natural decay and weathering.

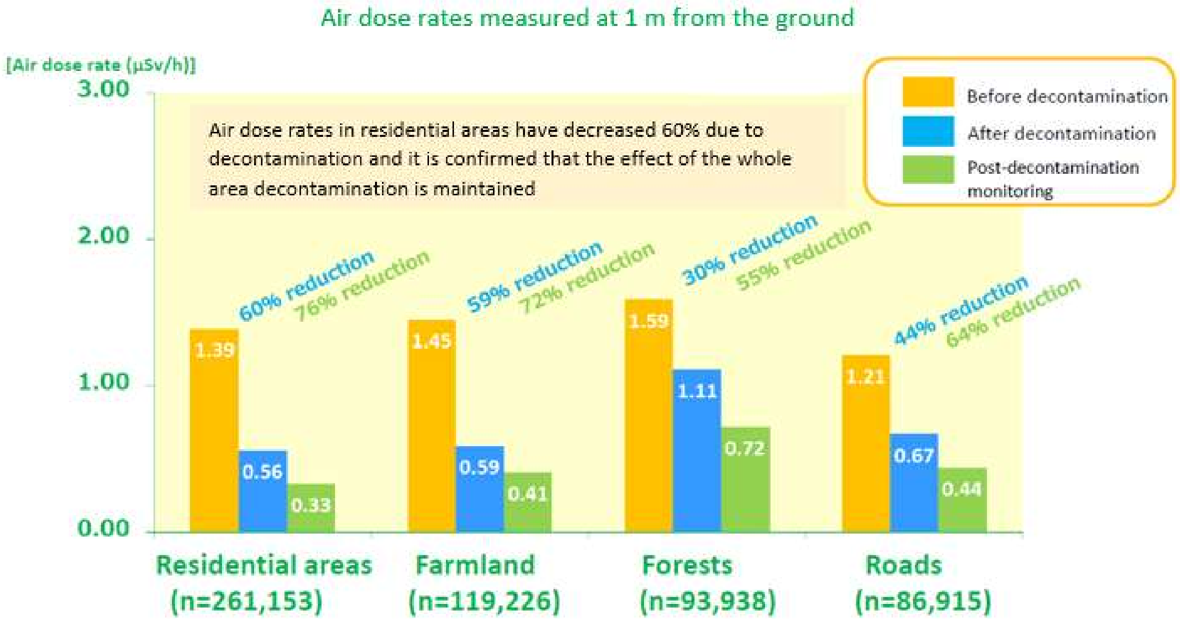

FIG. 8. An average reduction of air dose rate by land use in the SDA (reproduced from [35] with permission)

4.3.2. Intensive Contamination Survey Area remediation

Full-scale remediation of the ICSA based on the remediation implementation plan was completed in March 2018. In a total of 92 municipalities, the cumulative total number of workers was about 17 million persons, and the budget was about 1.4 trillion[6] yen including about 1.3 trillion yen inside and about 50 billion yen outside the Fukushima Prefecture.

The average air dose rate in the Fukushima Prefecture ICSA was reduced from 0.53 $\mu Sv.h^{-1}$ to 0.30 $\mu Sv.h^{-1}$ right after remediation. The average air dose rate reduction was 42% in residential areas, 55% in schools and parks, and 21% in forests compared to right after remediation. The air dose reduction by land use in the Fukushima Prefecture ICSA is summarized in Fig. 9.

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[6] Approximately US $12.7 Billion

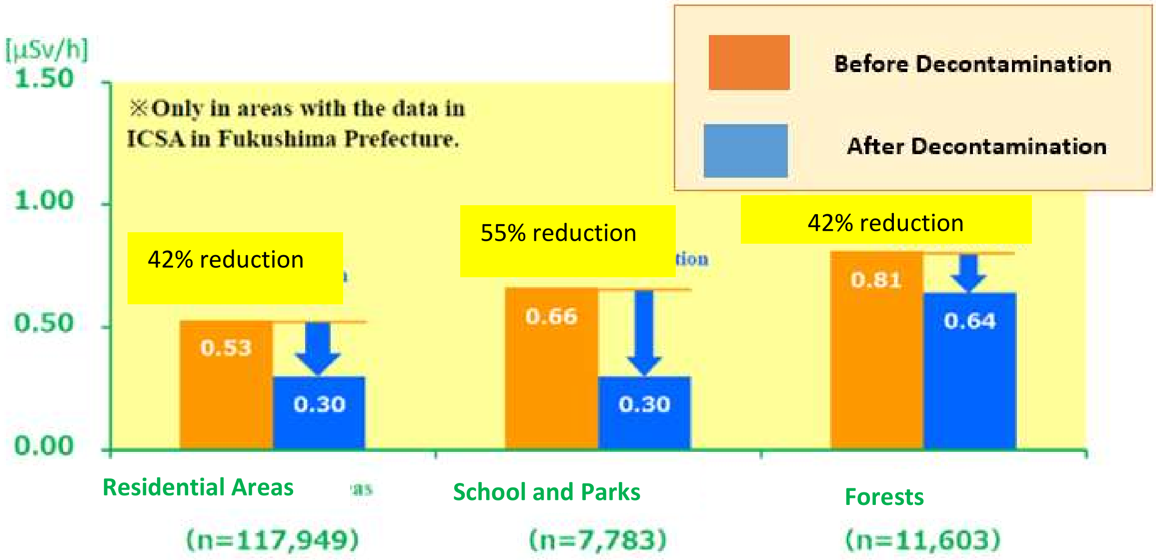

FIG. 9. An average reduction of air dose rate by land use in the Fukushima Prefecture ICSA (reproduced from [35] with permission).

The effectiveness of environmental remediation in the ICSA is estimated by comparing the air dose rates with and without remediation using 126 000 monitoring data. The air dose rate with remediation in Fukushima Prefecture ICSA was reduced by approximately 38% compared to the air dose rate without remediation in March 2016.

4.4. FOLLOW-UP REMEDIATION (SUPPLEMENTARY REMEDIATION)

The MOE published a basic policy for supplementary remediation in Dec. 2015 to address the cases where radiation levels have not been reduced to the target levels after the full-scale remediation. This policy specified that site-specific remediation would be conducted based on the monitoring activities. In the SDA, the supplementary remediation could be conducted if the air dose rate didn't decrease below the derived level (3.8 μSv.h^{-1}) of the evacuation criterion (20 mSv/a). Following the MOE's policy, supplementary remediation has been carried out at about 10 000 residences (as of October 2017). The main supplementary remediation locations have been connected to the water pathways, such as slopes, rain puddles, roadside gutters, and around a 50% reduction in air dose rate was achieved.

The evacuated areas need to have dose rates lower than 20 mSv/a in order that evacuation orders for the areas can be lifted. However, some places with the estimated annual dose rates higher than 20 mSv/a still existed in residential areas even after remediation was carried out. Therefore, follow-up remediation has been implemented in limited locations. For other areas, follow-up remediation was implemented under the consideration of rationality and technical feasibility and by identifying the contaminated spots (e.g. in the corner of houses with the pathway of rainwater and forests nearby houses and roads). An overview of follow-up remediation is shown in Fig. 10. After the follow-up remediation, continuous monitoring was conducted until the designation in the SDA was lifted. In parallel with monitoring, communication with residents took place intending to ease anxieties in local communities. It is important to emphasize that the MOE made use of individual doses to support the decision making about the need to have follow-up remediation implemented.

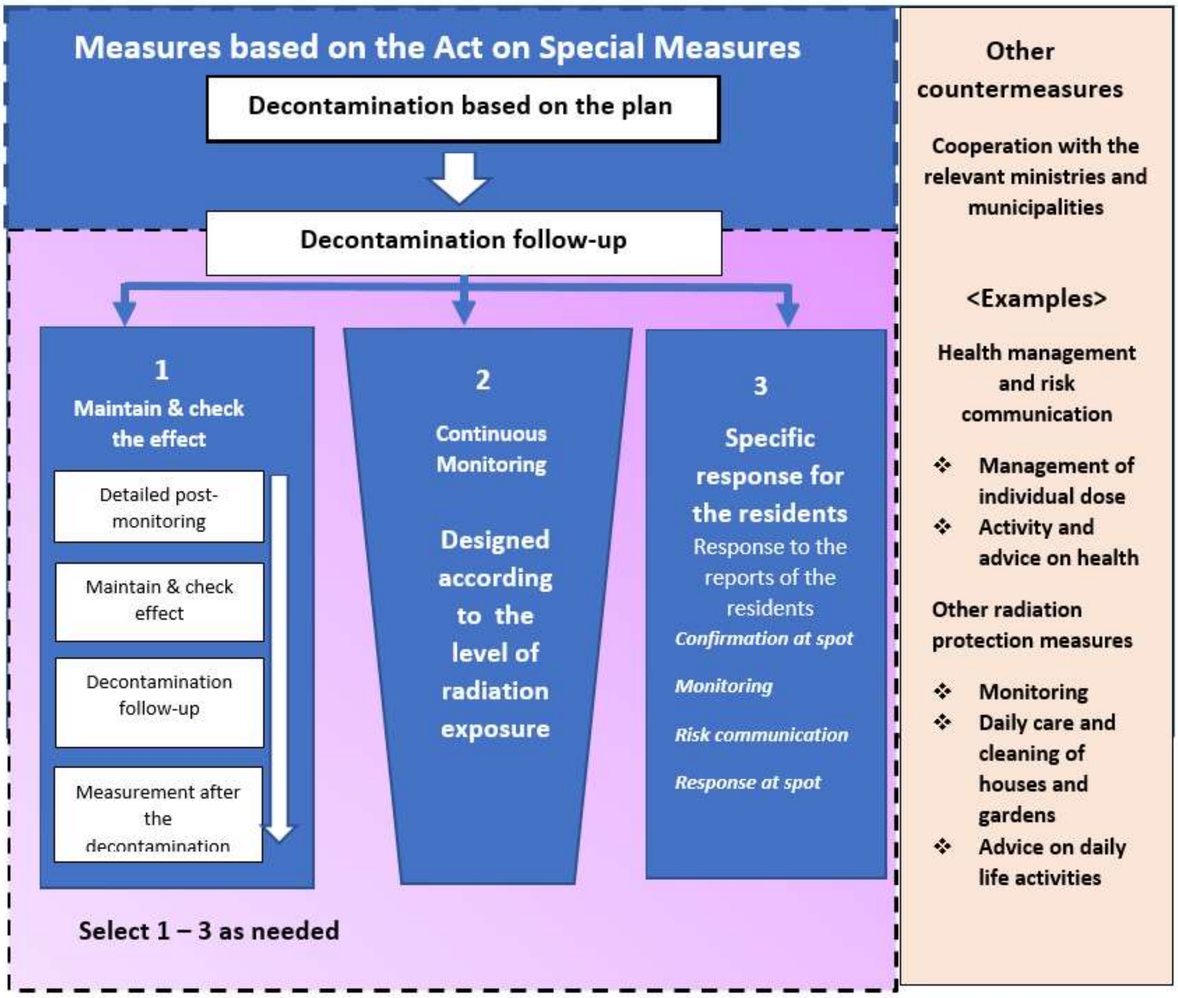

FIG. 10. An overview of follow-up after decontamination (reproduced from [35] with permission).

4.5. VERIFICATION OF REMEDIATION

The reduction of air dose rate by remediation was verified and confirmed in agreement with residents during field visits implemented by the verification committee, a third-party entity established in each municipality and composed of experts, municipality staff, and community representatives.

4.5.1. Role of verification committee on remediation

In the SDA, the 'Committee for the Verification of Decontamination' was established by local governments. Verification by these committees has been conducted in each municipality before orders were lifted by the central government. The committees were tasked to investigate the current situation of dose reduction and the prospects for further reduction. Some of these committees held discussions on community recovery. Those included aspects related to infrastructure for returnees (e.g. provision of public housing, medical care, nursing care, schools, shops, drinking water, wastewater, electricity, roads, railways etc). The committees' activities also included informing residents of the situation and collecting input of experts on the topics necessary for resuming 'normal' living after returning home, as well as the lifting of evacuation orders, and reconstruction.

An investigation committee has been widely organized in the SDA, i.e. in the Naraha Town since 2015, the Kawauchi Village since 2016, the Iitate Village since 2017, the Minamisoma City since 2014, the Katsurao Village in the framework of Reconstruction Committee since 2011, the Kawamata Town since 2015, the Namie Town since 2016, the Tomioka Town since 2015, etc. Each committee summarized the results of the conducted investigation and other issues relevant to revitalization and placed further requirements for remediation from the standpoint of residents. The main agenda of verification committees was the remediation results, recommendations of experts, and guidelines for the next steps.

4.6. EFFECTIVENESS OF REMEDIATION METHODS

The air dose rate changes over 2014–2016 within the SDA were analysed using the Bayesian data integration approach and the results showed that the environmental remediation contributed significantly to reducing air dose rates. Results also showed that the air dose rates were decreasing consistently across the region and the reduction rate was slowest in the forest and fastest in the town area [42].

The air dose rates in the living environment were also measured using the walking survey and car-borne survey systems within an 80 km radius of the Fukushima Daiichi NPP between 2013 and 2016 [43]. The results showed a decrease in air dose rates by 62% in the 42 months from June 2013 to December 2016, which was beyond what would be expected if only the physical decay of radioactive caesium was considered. The results also confirmed that the air dose rate reduction in urban areas was slightly larger compared to other areas such as forest and farmland [43, 44]. The faster reduction of air dose rate has been also reported by other studies [45]. The effectiveness of remediation has also been confirmed in the Tomioka Town within the DRZ in the Fukushima Prefecture [46]. This study also showed that the air dose rate decreased by 71.9% within one year of remediation efforts in areas where the initial median dose rate was of the order of 1 $\mu Sv.h^{-1}$ in the remediated area (e.g. at the Yonomori District).

The extent of the areas in the SDA and ICSA that required remediation was about 1,150 km^2 (with 11 municipalities) and 24 000 km^2 (with 104 municipalities), respectively [35]. The affected populations were about 80 000 in the SDA and 6.9 million people in the ICSA [35]. It is interesting to observe that the area to be remediated in the ICSA was almost 20 times larger than the one in the SDA. However, the total remediation costs were similar for the SDA and the ICSA i.e., Y1.5 trillion and Y1.4 trillion as of FY2018, respectively. These results may be attributed to the fact that more aggressive remediation methods were applied in the SDA to remove contaminated soil that showed higher radioactivity levels when compared to the ICSA. It can be suggested that the remediation methods used in the SDA required more time and effort for implementation. The volume of soil that had to be managed as waste after remediation in the SDA was approximately 9.1 million m^3. In the ICSA, this amount was of the order of 7.9 million m^3 as of March 2018. As a result, the waste management costs per remediated area including storage and transportation was higher in the SDA than in the ICSA.

Some studies raised concerns about the effectiveness of remediation of forests. In particular, the effectiveness of forest remediation by removal of the floor litter layer was doubted [47]. A pilot-scale study to assess the remediation effectiveness in a deciduous broadleaved forest in Fukushima was conducted for three years [47]. The study showed that, for Japanese forest ecosystems, remediation by litter-removal can only be successful if it is implemented quickly (within 1–2 years after the accident). It has also been shown that initially, the remediation reduced contamination level but four months later the level increased to the same level of untreated forest area [48]. The study suggested this re-entrainment of the contamination was due to torrential rain events.

The remediation cost associated with agricultural land within the SDA was up to 80% of the total cost for the whole area [49]. The main methods in the remediation of this medium were topsoil removal (with and without covering the remaining soil with a clean soil layer and, interchanging a topsoil layer with a subsoil layer), and in situ mixing of the topsoil. Topsoil removal and interchanging a topsoil layer with a subsoil layer resulted in similar reductions in the air dose rate. Reverse tillage was relatively less effective. Results also showed that the effectiveness of soil remediation using these methods depended on: i) the initial depth distribution of radiocaesium within the ground, ii) on the size of the remediated area, and iii) on the mass per unit area of remediated soil [50]**.** Since caesium bounds strongly to clay minerals within the top few centimetres of the soil, stripping topsoil removed the radioactive caesium from the contaminated surfaces. Covering with a clean soil layer following topsoil removal resulted in added benefits of reducing the exposures from residual radioactive caesium and providing fertility for agricultural product cultivation compared to bare surfaces. Limitations of the remediation method of the agricultural area using the removal of surface soil followed by soil dressing and ploughing have been pointed out [51]. The study found hot spots of radioactive caesium from insufficient mixing of the original and the dressed (fresh layer of) soil, noting that the dressed soil had low fertility compared to the original soil. The study further proposed adequate soil mixing to avoid hot spots and an additional supply of fertilizer following the remediation. The soil layer interchange and soil mixing methods reduced air dose rates by shielding and redistributing radioactive caesium deeper into the ground. The benefit of these methods is the minimal amount of waste compared to topsoil removal.

Several studies have shown that most of the caesium in the soil is vertically distributed within 5 cm of topsoil since the initial contamination. Horizontal distribution of surface caesium has been observed and it is mostly due to rain runoff and potentially resuspension and redeposition from remediation and meteorological activities [52]**.** Results obtained for the remediation of different soil types showed that remediation methods are effective for soils rich in silt and clay but for sandy soils [53]**.**

Water reservoirs are important for the remediation of agricultural land. In the Fukushima Prefecture, there are over 1,000 water reservoirs for both agricultural and surface water management. Radiocaesium contamination of sediment cores was also investigated, and distinct radiocaesium peaks representative of the initial post-accident wash-off phase were found [53]. The sources of radiocaesium particulate matter are cultivated sources (farmland), forest, and subsoil sources and they are responsible for contaminated sediment with 48 +/- 7%, 27 +/- 6%, and 25 +/- 4%, respectively [54].

4.6.1. Remediation work in progress

At the time of the writing of this report, the remediation works in the DRZ was still in progress. The effectiveness of remediation in these areas still need to be assessed. The national government designated the SRRB in the DRZ, which heads of municipalities plan to promote the construction of the SRRB aiming to lift evacuation orders (to allow returnees). The municipal governments' development plans are reviewed by the national government. Based on the approved plans, the MOE implements remediation and waste disposal treatment, and the Reconstruction Agency of Japan implements projects to construct critical infrastructure. Municipalities will get tax benefits related to capital investment.

The policy and recovery progress in the SRRB are further described and discussed in Section 8.

4.6.2. Public expectation of remediation

The residents in Fukushima were confused by the meaning of the government's long-term goal of 0.23 $\mu Sv.h^{-1}$. Many Fukushima residents conceived that any place with a dose rate higher than 0.23 $\mu Sv.h^{-1}$ was deemed unsafe. As a result, the guidance for residents to live or return in areas with dose rates higher than 0.23 $\mu Sv.h^{-1}$increased distrust in the government among residents. This misinterpretation of the target dose rate was connected to the expectation of remediation. In the initial remediation efforts, Japanese people expected that remediation would produce an immediate reduction of dose rates to 0.23 $\mu Sv.h^{-1}$. However, this goal was meant to be achieved in the long-term as a result of the combined effects of remediation, physical decay and weathering. The Japanese government decontamination standard created confusion in society that led to a breakdown of trust [55]. This distrust in governmental authorities caused by misinterpretation resulted in the lack of confidence in the remediation efforts. Residents thought that the work was not implemented properly or the appropriate information and explanations before and after the implementation was lacking. Many questions were raised from the stakeholders about the effectiveness of the government's remediation activities. However, at the end of the day, the general public considered that remediation was necessary regardless of the observed radiation dose levels and as a result, some stakeholders demanded remediation regardless of the radiation level measured in their living environment [55].

4.6.3. Impact of remediation in the affected communities.

Following the Fukushima Daiichi NPP accident, the affected communities have tried to recover from the damage with a sense of togetherness (i.e. the recovery is focused on the community as a whole community). The remediation efforts can contribute to reducing radiation risks, relieving anxiety, and de-escalate perceptions of fear and harm to individuals and families. The outcomes of remediation can increase the trust of locals in national government and such approaches can lead to significant improvements in the effectiveness and acceptability of long-term radiation risk management [56,57]. This section intends to provide information on how the full-scale remediation project influenced the community beyond its primary objective of radiation reduction.

Environmental remediation has impacted the community in various ways beyond the reduction of radiation dose. Remediation projects present significant logistical challenges including availability of a labour force, equipment, supplies and associated needs for workers such as food, lodging, add health care. On the positive side, making these resources available will benefit the economy at the local level as municipal, prefectural and central governments need to hire workers from local communities including residents, construction workers, farmers, etc. This effort also included supplies, lodging, and equipment that were purchased and rented locally as much as possible [58]. Therefore, efforts to provide local resources for the remediation project contributed to the economic growth of the affected area.

On the other hand, some communities, such as Minamisoma City, experienced a shortage of labour for the recovery activities. This shortage of labour was caused because the population of the working-age left their communities following the Fukushima accident and many people of working age had to care for senior family members and friends. As a result, the shortage of labour negatively impacted various areas of recovery including remediation, service industries, industrial enterprise production, etc. To overcome this problem, a large number of workers had to be hired from outside local communities and this influx of a large number of workers to the local communities created high traffic volume as a result of workers commuting and adding to the transportation of materials related to the remediation activities.

Environmental remediation generated a large volume of contaminated material (eventually classified as radioactive waste). The generated remediation waste has been stored within the community boundaries due to the unavailability of a disposal site or designated storage site. The residents raised concerns over the remediation waste sitting within their communities. In some areas, such as Date City, the incinerable wastes produced a noxious smell from the decomposition of organic waste as a result of delays in waste transportation out of the community. To respond to that situation, the city constructed a temporary incinerator to process the incinerable waste and charged the cost to the TEPCO. The challenges of waste management are discussed in Section 5.

It is evident that remediation influences the post-disaster community recovery in public health, safety, social, cultural and economic perspectives. The effects of radiation-related countermeasures on people's anxiety and well-being among residents of Marumori Town, Igu County, and Miyagi Prefecture were studied. The results suggested that remediation helped reduce the anxiety of residents after the accident and further contributed to an increase in residents' subjective well-being [59]. It has been emphasized how critical a holistic and cohesive approach is for long-term management to recover sustainable livelihoods and for social re-integration. Both actual risks and public perceptions of risks need to be carefully assessed in the process of environmental remediation. Further research is needed to understand how to design environmental remediation for the most effective outcomes of post-disaster community recovery.

4.7. LESSONS FROM FUKUSHIMA REMEDIATION

The Fukushima Daiichi NPP accident was an unprecedented event for the Japanese government. The MOE as well as other central government ministries and local municipalities faced various challenges during the remediation of the contaminated areas. Many challenges had been effectively addressed via creative and transparent approaches throughout the remediation planning, implementation, and verification. These identified challenges and resolutions from the Japanese government will help decision-makers and responders prepare for similar types of responses in the future in the unlikely occasion of a similar event. This section summarizes some of those challenges and lessons.

4.7.1. Holistic preparation of remediation

Remediation of contaminated areas, in general, requires a series of technical activities including characterization of different media and materials, application of remedial solutions, and waste management. Each activity is closely connected to each other and influences the path of the subsequent ones. Therefore, it is important to plan the overall response holistically by considering how the results of individual actions would impact the final status of the response.

Following the Fukushima Daiichi NPP accident, the Japanese government focused on environmental remediation to protect the public and to help recover the affected communities. However, the remediation efforts started without the necessary identification of the disposal site for remediation wastes. As a result, the generated wastes have been stored adjacently to the areas being cleaned or transported and stored within the vicinity of the affected community – the so-called Temporary Storage Sites (TSS). Even after the completion of full-scale remediation, piles of remediation waste bags were stacked within the boundaries of the communities from which the wastes have been generated. As an intermediate solution, the MOE came up with an approach to store all remediation waste in one place called the Interim Storage Facility (ISF). The ISF will be operated for 30 years till the final disposal site is made available. The progress of the ISF construction was also delayed mostly due to the process that has to be put in place for land acquisition from the evacuated landowners. Without a place to go, waste transportation out of the TSS's was delayed, especially in the ICSA. This delay caused consequences that impacted the community's recovery. For example, incinerable wastes were separately stored and supposed to be transported out of the TSSs to the ISF or other facilities within three years. However, due to the delay of waste transportation to the ISF, the incinerable waste got composted and generated unpleasant odours in the community and resulted in continuous complaints and anger from the residents. The local government had to act to overcome this situation and have the waste incinerated by using the existing incineration facilities or constructing temporary incineration facilities (TIF).

As of 2020, there were yet many waste storage sites to be emptied by the MOE with the sites being returned to their original purposes. The transportation of wastes from individual storage sites (initially more than 150 000 locations) required careful planning and coordination between central and local governments (especially within the ICSA) to safely transport wastes throughout already remediated communities without disturbing the local community with the associated nuisances such as intense traffic of trucks. In addition, these multiple steps of waste transportation demanded supplementary resources such as workers and equipment e.g. trucks and heavy machineries.

Japanese remediation and waste management challenges demonstrate the importance of holistic planning of response emphasizing the need for a waste management plan as early as possible. Effective decision-making in the waste management areas can offer significant cost reductions. Decision support tools are currently available, and they can help estimate the type, radioactivity level, and amount of waste as a function of remediation methods [60-62]. Information from these tools can help in planning how to manage the remediation waste but will also inform decision-makers and members of affected communities on the consequences of individual remediation solutions such as the amount of wastes being generated, one of the obvious consequences of decontamination related activities. In addition, these tools can be further improved by incorporating waste reduction options such as waste treatment technologies including potential recycling options. In conclusion, improved tools can help decision-makers in assessing large-scale remediation projects more holistically to optimize the resource allocation throughout the response. Holistic preparation is a critical component of any generic remediation plan so that potential options can be made readily adaptable as well as optimized to specific situations throughout the course of remediation implementation.

4.7.2. Coordination

Coordination of all relevant parties (national and local governments, stakeholders, and remediation operators) is important to incorporate future development of the community for remediation work. For the SDA, the environmental remediation needed close coordination between central and local government. Coordination among central government ministries was essential to deal with overall recovery in addition to remediation. The coordinated ministries were, for example, the Ministry of Land, Infrastructure, Transport and Tourism, the MAFF, and the RA. For the ICSA, various organizations were responsible for the implementation of remediation work on land that was managed within the ICSA. These organizations included the national government, the individual prefecture, the municipality, and a person or entity as set forth in the ordinance of the MOE e.g. independent administrative agencies, national institutes, such as the National Institute of Environment Studies, JAEA and national universities.

The MOE's coordination with local communities was the key to securing remediation workers and supplies including food supply and equipment. In the SDA, there was no critical infrastructure available such as water, sewerage system, waste management facilities, etc. The MOE's coordination with neighbouring governments was critical to get access to the resources and facilities that were required for remediation implementation.

For effective coordination, MOE personnel were stationed in the Fukushima Prefecture since 2011. The activities of the local office improved the stakeholder engagement and supported the remediation of municipalities in the ICSA. The MOE established the Fukushima Decontamination Promotion Team, then the Fukushima Office for Environmental Restoration, and currently, it became the Fukushima Regional Environment Office with new branch offices in several different locations. The roles of the MOE have continuously increased to support the ICSA remediation, implementation of remediation within the SDA, and management of remediation waste. The number of the MOE personnel increased from 40 in 2011, to 591 in 2017, many of them working closely with local communities and responding to the growing scale of remediation work.

4.7.3. Selection of remediation methods

As observed from Japan's environmental remediation efforts, there is no single method that can work for all surfaces and media. When a wide area is contaminated, many different remediation methods will be needed because of various types of surface and media in the contamination zone. For example, in Japan, residential unit remediation was separated into several sections: roof, gutter, wall, ground items (fence, playground, etc.), garden, and street drain. Each section was remediated using different methods depending on the surface types.

Within the same surface type, multiple remediation methods were also made available. These methods have different technical and operational characteristics. These characteristics include decontamination efficacy, application rates, required expertise, different types of equipment, waste types and amount, etc. Some methods have higher removal efficacy and generate variable amounts of waste volume. Some methods require extensive labour and others may need special equipment and operators. The remediation methods are selected via a balanced consideration of all these factors. The application of specific remediation solutions may be hampered by site conditions. For example, some sites may not have enough waste storage or management capability, so remedial options to be implemented in these circumstances may be associated with minimal waste volume generation. Some sites may have difficulty in supplying certain types of equipment and experts. Some may have limitations in supplying essential resources such as water and electricity. Conversely, some sites may contain critical infrastructure and may call for rapid remediation to reduce the impact of the impairment of such services on the wider community.

It was also observed from Japan's remediation work that the same remediation methods may also have variable efficiency in caesium removal even though they are applied to the same surface. This is because caesium contamination. For example, high-pressure washing was effective for paved road surfaces in the early remediation work. However, radioactive caesium migrated into the paving material due to rain and because of that more intrusive remediation methods such as surface scraping by shot blasting became a more effective approach than high-pressure washing in those cases.

The conclusion is that decision-makers will need to consider remediation methods based on site-specific information and all technical and operational characteristics of available remediation methods. Finally, it is imperative to communicate the selection process and the resulting decisions to the affected stakeholders (e.g. landowners, communities, local government, etc.) and get their understanding and, as much as possible, their support prior to the implementation of the remedial activities. This is seen as a critical process and potentially time-consuming though of great relevance for the success of the overall work.

4.7.4. Importance of testbeds

Many remediation methods have been developed and tested in numerous contaminated sites in different countries [63-66]. However, the contamination conditions may differ from the ones in which the methods have been tested and applied. These methods may not be as efficient as they have been documented and they need to be verified for their technical and operational factors specific to the contamination situation being dealt with (in a real situation) before full implementation. During the verification, the tested methods can be further modified or adapted to the available equipment and to a labour force of varying skills, according to local availability. In addition, this process can help developing the expertise among practitioners, researchers, and government officials for remediation.

Prior to the full-scale remediation, the Japanese government conducted field verification (called Demonstration Projects) using the testbed for the remediation methods that could have been applicable to Japan's contamination situation. Examples of the Projects are shown in Table 5. Despite the Japanese government was not yet fully prepared to remediate the contaminated area, these projects provided essential information to plan and implement the full-scale remediation including site characterization, decontamination, and waste management. The information from these projects included effectiveness of technologies, cost, time, intrinsic difficulties, safety considerations, waste amounts and types, labour requirements, equipment etc. These results were used to identify the applicability, availability, and workability of the selected technologies for full-scale remediation that in turn require an enormous amount of resources. The results from the Demonstration Projects were used to plan the budget for the full-scale remediation and the information was subsequently used by the municipalities for their resource planning in the ICSA. The compiled results from the Demonstration Projects were organized and published as the remediation guidance documents for local governments and operators.

TABLE 5. EXAMPLES OF TESTBED PROJECTS BY JAPANESE GOVERNMENTS

Project title	Institute and years	Purpose
Decontamination Model Projects	JAEA, Nov. 2011	Limitation and effectiveness evaluation, efficiency, waste type and amount, cost, time, labour, difficulty, safety, required resources, monitoring to identify hotspots, the impact of environment on implementation, prevention of recontamination, project management, waste reduction, remediation worker safety, stakeholder concerns on remediation.
Decontamination Technique Demonstration Projects [31]	MOE, Dec. 2011-2015	Evaluated 67 methods for efficiency and effectiveness at field setup (yearly Request for Information and Request for Proposal) focused on new remediation technologies; Assessment included applicability, effectiveness, cost, time, safety.
Fukushima Prefecture Full-Scale Decontamination Model Projects [31]	Fukushima Prefecture in Nov. 2011	Evaluated 49 remediation methods for effectiveness focused on radiation dose reduction in living area, time and cost efficiency, waste amount and type, safety, public water impact.

4.7.5. Role of experts

The timely delivery of expert opinion for the public welfare is critical to support the recovery of the impacted communities from the disasters. The public expects the experts to deliver objective opinions through an independent and transparent process. The importance of expert participation during the remediation has been emphasized based on the experience of the management of contaminated areas for the sustainability of community recovery.

Immediately after the Fukushima Daiichi NPP accident, Japanese experts immediately acted to support environmental remediation by providing technical knowledge to the public and the government. The experts including academic societies have provided essential information for decision making based on the scientific knowledge throughout the environmental remediation project. Some specific examples are offered below:

- Experts helped the decision-makers such as mayors of local government to identify and implement the remediation technologies and to interpret the results;
- They also helped the government officials to communicate with the stakeholders and the general public;

- They supported the translation of foreign documents into Japanese, so the government could identify the applicable remediation technologies, such as those contained in the EURANOS handbook;
- The JAEA designed and implemented testbeds to verify the remediation technologies and to generate operational information for planning and implementation;
- The experts helped to develop remediation schemes for the municipalities in the ICSA and review those plans;
- Experts also assisted in developing decision supporting tools for remediation to aid decision-makers to assess the remediation plans in relation to their effectiveness in terms of radiation exposure reduction. The calculation System for Decontamination Effect (CDE) predicts the air dose rate after remediation and evaluates the remediation effects. The Restoration Support System for the Environment (RESET) predicts the remediation effects on a simple operation screen on the internet for municipalities in the SDA and the ICSA to use [61,62]. The TEPCO and remediation companies developed three dimensional (3D) remediation effect prediction system considering terrain and sky shine, etc. The results have been used to obtain consent from residents

4.7.6. Stakeholder engagement for remediation

Clear and transparent communication with stakeholders helps to improve the public trust and as a result, improve effective decision making during the remediation progress overall. Throughout the environmental remediation process, it is important to establish the conditions and to implement the means that will allow the effective engagement of the affected population by the government authorities for effective community recovery [67].

Japan's remediation process included multiple steps of stakeholder communication. Though these steps might have varied between the SDA and the ICSA and among municipalities in the ICSA, the main goal of stakeholder communication was to provide accurate information of remediation work to stakeholders so they could make appropriate decisions for remediation of their properties. Municipalities in collaboration with community groups selected and developed approaches by considering the characteristics of specific situations. As mentioned above, stakeholder communication steps were time-consuming and labour intensive with a lot of effort being required to prepare the meetings. These efforts included stakeholder identification, preparation of meeting contents, and materials to be used in these events. At the beginning of the SDA remediation process, extensive time and efforts were necessary to identify and locate the evacuated landowners and business owners to get their access agreements and consents. Because of that, the MOE worked with local municipalities for locating the evacuees. During the conversations, information had to be presented in plain language to help stakeholders understand the remediation process since the remediation terms and information were often highly technical. In addition, stakeholders' interests were beyond the technical and safety aspects of remediation and the communication had to be prepared to accommodate other stakeholders' interests such as compensation and associated emotions. The stakeholder engagement efforts and lessons from the Fukushima Daiichi NPP accident response are further described in Section 6.

4.7.7. Remediation workers and work environment

The size of the area that required remediation was initially fixed at approximately 24 000 km^2 and covered many jurisdictions (8 prefectures with 104 municipalities in the ICSA and 11 municipalities in the SDA). Because of the large area and labour-intensive approaches for remediation, the full-scale remediation required a large number of workers (nearly 80 000) for more than 5 years. Construction companies became the lead remediation performers who have historically conducted various large-scale civil projects.

This is because the nature of construction work is similar to remediation work in terms of project scale, required equipment, techniques, etc. In addition, these construction companies have the experience to recruit and train a large number of workers. However, it was still challenging to recruit and manage the number of workers and to retain experienced workers to complete the planned remediation activities on time. The trained and experienced workers became valuable assets for high quality and timely remediation. Many experienced workers often left their remediation jobs due to the labour-intensive tasks in hard to work environments such as extreme weather conditions. New workers required additional time and training to be able to conduct quality tasks by getting various safety and skills and also field experience. To mitigate this recruitment issue, hiring from the local community including residents, construction workers, farmers, etc. was promoted. Because many workers conducted remediation activities on a daily basis, several associated challenges were identified, and they are summarized in Table 6.

In summary, coordination with local communities was the key to resolving most of the challenges, including local hiring and local procurement of supplies (e.g. food and equipment). The positive impacts of remediation work were observed on the local community economy and employment.

TABLE 6. CHALLENGES AND RESOLUTION FOR REMEDIATION WORKERS AND WORK ENVIRONMENT IN JAPAN

Challenges	Detail	Japanese Government Actions
Securing worker's basic needs in the evacuated area	In the SDA where infrastructure was not available, the workers had difficulties due to lack of food and water supply and long-distance commuting.	The MOE coordinated with neighbourhood municipal governments to get access to the resources and facilities.
Securing remediation resources	Equipment, material, and workers for remediation were difficult to supply due to the parallel earthquake and tsunami recovery work. During the initial remediation work, equipment was difficult to rent from the leasing companies due to the concerns about radioactive contamination.	Substitute equipment by renting farming equipment and hiring local farmers
Managing worker records	It was difficult to manage administrative information and records for workers such as work hours, doses, training information, etc.	The remediation contracting companies established an implementation system to manage decontamination workers. In some cases, facial recognition and fingerprint authentication devices were used.
Minimizing local community impact	The local communities in the ICSA experienced high traffic volume due to worker commuting and remediation related transportation.	The MOE, municipalities, and contractors made various efforts to reduce the local traffic load including ; prepared lodging facilities within commuting distance in the prefecture, in some cases, special accommodation in the Preparation Areas for Lift of Evacuation Orders, using commuter buses, staggering commuting times by setting different work start times, and dispatching traffic guides, etc.

4.7.8. Hotspot identification

In Japan's remediation works, caesium hotspot removal was the most effective approach to reduce the radiation level with minimal effort. Central government agencies and local municipalities have identified the common hotspot areas from the remediation experience in various sites.

The JAEA's Decontamination Model Projects tested monitoring procedures to identify hotspots and the MOE developed the Guideline on Handling Localized Sites Contaminated by Radioactive Materials in March 2012 [38] to support municipalities to identify hotspots. For example, hotspots were usually found near the discharge areas of the rainwater flows which were the common pathways for the transport of caesium and caesium attached particles.

During remediation of roads, interlocked gaps were also found to serve as hotspots by transporting and accumulating scraped (blasted) material. However, if unexpected hotspots were identified, then it was challenging to detect them without full scanning of the remediation area, which would have been a time-consuming step with existing survey tools and methods. With the progress of the remediation activities, survey tools such as Gamma cameras became available for local municipalities, but the results were often difficult to interpret leading to difficulties in pinpointing the hotspots due to the limitations of the two-dimensional display instead of a three-dimensional one. A contamination map can be visualized three-dimensionally on a three-dimensional (3D) topography model acquired by a Light Detection and Ranging system. The test of this system in the DRZ successfully demonstrated 3D visualization of several hotspots. This system will be helpful for wide-area remediation by quickly identifying hot spots. Large scale radiation mapping created from aerial or systematic ground monitoring has value in identifying major areas requiring remediation planning. As remediation progresses, a more specific evaluation of local radiation conditions will be necessary to effectively establish detailed remediation strategies. These newly developed tools will help monitor and survey site-specific contamination conditions.

4.7.9. Importance of availability of critical infrastructure

Environmental remediation relies on critical infrastructure such as transportation, utilities, medical facilities, etc. When such critical infrastructure is closed or restricted due to contamination, then a wider community than the one living in the contaminated area will be impacted. So, the remediation of areas/sites that host critical infrastructure was set as a high priority. For example, the Joban Expressway is a critical infrastructure that connects the North and South portions of Northern Japan. The Great East Japan Earthquake destructed some parts of the Expressway. So rapid restoration of the Expressway was crucial for the nation and there were strong local requests also. However, because the annual dose in some paths of the Joban Expressway initially exceeded 20 mSv/a, it was necessary to remediate the high radiation areas. The MOE conducted the model Demonstration Project in March 2012 to reduce the radiation level to less than 50 mSv/a. Full implementation of the Joban Express remediation started in December 2012 and was completed in June 2013.

Remediation involves utilities such as water and electricity, roadways for transportation, and facilities to be used as a base camp and other general purposes. However, these essential needs are not readily available in an evacuated area. In January 2012, the MOE with the support from Japan's Self Defence Forces remediated the critical facilities to have them used as a base camp for remediation including municipal offices, community centres, access roads, and water infrastructure.

4.7.10. Impact of environmental conditions on remediation implementation

The application and effectiveness of remediation methods were greatly impacted by extreme weather conditions such as extreme cold and hot weather, typhoon, monsoons, etc. Some remediation methods were directly hampered by weather such as muddy conditions following precipitation and icy/snowing events. Such conditions had a direct effect on the removal efficiency of some techniques and also on their workability. There are numerous challenges and lessons learned acquired in this regard throughout the remediation work. Here some examples are listed.

- Rain events: rainfall impacted remediation work by providing a shielding effect and causing uncertain air dose rate measurement, increasing waste mass due to the related increased in moisture content, washing away piled remediation material, generating leachate from TSS, producing an accumulation of rainwater at TSS, and washing away container bags by heavy rain (e.g. flooding and typhoon). Wet soil behaved like mud in waste bags, which were not amenable to be stacked safely. As a solution, gypsum was added to harden the material in the waste bags. Topsoil removed surfaces required additional care to prevent erosion and soil loss from precipitation by treating or covering (gravel, tarpaulins, etc.) the remediated areas [31];
- Snow and cold weather: snow also provided a shielding effect with uncertain air dose rate measurements, deteriorated work quality and increased concerns about safety issues. Under cold weather, machines could not remove the required thickness of soil due to the frozen topsoil layer;
- Hot weather: remediation workers required resting areas to avoid high temperature and sun exposure during the summer;
- Others: After multiple years of evacuation, vegetation grew significantly in some areas in the SDA and needed additional steps to remove overgrown vegetation by weeding and cutting brush and shrubs. Remediation methods in the SDA had been changed as caesium migrated deeper into the surface or media. So more intrusive remediation methods were used e.g., from brushing to blasting. Some areas such as mountainous villages had limited access to transportation and accommodation for remediation workers.

4.7.11. Remediation of natural areas

Forest accounts for a significant portion of the contaminated land affected by the Fukushima Daiichi NPP accident. The initial approach for remediating the forest was the removal of sedimentary organic matter within 20 m from the edge of the forest near the living areas to reduce the air dose rates in these places as well as to protect the remediation workers. Remediation methods included removal of undergrowth and brush, fallen leaves and other organic residues. In addition, forest remediation approaches needed to consider forest types (e.g. evergreen, and deciduous forests) and seasons, because caesium contamination may differ for different tree types. Also, caesium seasonally migrates in the forest into various parts of trees and forest surface layers. Removal of radioactivity in the forest was physically challenging due to uneven surfaces and demanding labour-intensive work since heavy equipment could not be used. In addition, topsoil removal may result in soil erosion. If recontamination occurred due to soil runoff after remediation (soil removal), then erosion prevention measures were implemented (wooden fence installation etc.). The forest remediation approaches were further revised in 2012 by considering how the forests were planned to be used such as roadway, recreation, tourism, food source, industry, etc. Forest remediation was then designed by combining removal and controls of access frequency and time spent in that particular environment.

Since most of the contaminated forest areas were not remediated, the MOE, research institutes and universities assessed the potential transport of radioactive caesium from the contaminated forest area to the living environment. The results have not indicated any significant transport of caesium. However, there are still concerns that the current approaches may not be enough to rapidly recover the contaminated forests. Therefore, the Japanese government has established a special project team that was composed of all relevant government ministries to search for effective methods to restore forests, as discussed in Section 8.4.2.

In addition to the forest area, aquatic areas such as reservoirs, lakes, rivers, and riverbeds/basins were contaminated. Most of the radioactive caesium is attached and fixed to particles and flowed into the aquatic areas from the contaminated lands. The caesium particles then settled at the bottom of the lake or river. This does not constitute an immediate public risk because it is shielded by the water in the aquatic environment. However, with severe weather events such as typhoons and flooding, these radioactive particles may be disturbed and transported to other areas. Extreme drought may also lower the water level and increase the radiation dose to the near environment. Japan’s general approaches in the aquatic environment were to conduct regular monitoring and to search for response approaches based on observation and cumulative knowledge.

5. WASTE MANAGEMENT

5.1. INPUTS FROM IAEA–MOE MEETINGS ON WASTE MANAGEMENT

Since the first of the four IAEA–MOE meetings the management of large amounts of contaminated waste[7] generated during the remediation activities has been recognized as a major challenge in the overall remediation efforts, and specific aspects of managing such waste have been the subject of numerous discussions of MOE staff with international experts.

In the first of these meetings, it was stated that "it would be beneficial to establish criteria (that would allow for soil recycling) prior to the clean-up activities or implementation of soil volume reduction methods (prior to permanent disposal)". Section 5.7 is dedicated to the approaches and safety considerations of soil recycling.

It has also been pointed out that it was important to achieve a clear understanding of the distribution of radionuclides within the sewer systems, wastewater treatment plants and drinking water supply systems.

Another point that deserved attention was the need to integrate information on the amounts of wastes to be generated by different remediation approaches into the overall decision making. In this regard, the establishment of a decision-supporting tool that incorporates considerations on waste volume reduction options and associated assessment of its impact on final disposal was suggested. The need for such an approach is a crucial lesson learned from the remediation in Fukushima (see Section 5.8).

In the second meeting, with regard to recycled materials from decontamination used in the construction of roads, banks or coastal levees, etc., it was pointed out that the extent of the potential release of radioactivity to the environment should be addressed eventually by means of modelling exercises and subsequent monitoring. The demonstration and testing projects in soil recycling, that foresee monitoring of radionuclide releases from recycled soil are addressed in Section 5.7.4. Regarding the use of recycled materials (containing Cs-137) from decontamination work, construction workers would require radiation protection training to minimise external dose, as well as internal dose (e.g., from inhalation). In this respect, it was agreed that workers should be monitored while handling these materials.

The IAEA experts have also pointed out that setting waste acceptance criteria for the facilities that would receive decontamination wastes was an important issue that deserved due attention.

It was also suggested (in the third meeting) that the MOE could consider the possibility of publishing and/or making available information on the amount of waste produced by various decontamination techniques. This suggestion has not been addressed so far by the MOE due to limited resources which were allocated to other urgent issues of ongoing remedial activities. However, the dissemination of the valuable experience of the MOE can be further investigated in future collaborations with the IAEA.

Mixing and blending of residual materials with other materials of similar characteristics, (e.g. as part of construction materials for dams, roadbeds, or waste disposal cells on the footprint of the remediation site; or during ploughing of soil), may occur during remediation. It was advised by the

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[7] 'Waste' arising from decontamination activities includes soil, grass, leaves, branches etc. (See 5.2.3 for details.)

IAEA experts that such an approach could be considered when and where there is a need or convenience for enabling residual materials to be safely recycled or reused.

As the MOE moves ahead in implementing waste management activities and construction of waste management facilities (e.g. ISF, treatment plants, etc.), the IAEA team advised that the MOE consider conducting a safety assessment of these activities and facilities and have it evaluated by an independent agency. This issue is further addressed in Section 5.7.

In the fourth meeting, the IAEA team was informed that citizens were urging cities' mayors to remove the waste from temporary storage sites (TSS) and close these storage sites as soon as possible. In this regard, the IAEA team suggested that the MOE should carefully assess the potential for delays of the ISF construction and soil/waste transportation due to the simultaneous construction projects. The waste transportation issues, current status and plans for completing waste transport from TSSs to the ISF are discussed in Section 5.6.2.

5.2. GENERAL DESCRIPTION OF THE DECONTAMINATION WASTE MANAGEMENT TASKS AND PROCESS

The management of wastes generated by remedial activities in the off-site areas has proved to be a very complex and challenging task. Management of decontamination waste resulting from remediation of the off-site areas represented an unprecedented radiation safety, technological, economic and social task, which has never been encountered before. For example, though off-site decontamination works were carried out in the case of the Chernobyl accident, these works were carried out at a much smaller scale and have resulted in an estimated 30,600 m^3 of radioactively contaminated materials [68], which is approx. 500 times less than the amount of removed waste produced by post-accident decontamination works in the Fukushima Prefecture.

The decontamination waste is represented mostly by large volumes of material containing relatively low levels of contamination (mostly removed soil), which requires the application of specifically tailored approaches and techniques that are different to those used in routine management of 'normal' wastes produced by the nuclear sector. In particular, the storage, treatment and disposal of large amounts of decontamination waste required *ad-hoc* management strategies and technical solutions. Moreover, the issues related to storage, partial recycling and final disposal of decontamination waste are expected to extend long beyond the termination of remediation activities.

Key challenges were also related to the need to get consent for waste management activities (storage, transportation) and acquisition of land for waste management facilities from local authorities and landowners (some of them have moved to distant locations in Japan) and to address concerns of residents. The need to carry out decontamination work rapidly in multiple locations required efficient coordination and solving of associated logistical issues.

The key prerequisite to the timely and efficient implementation of remedial activities was the rapid establishment by the Government of Japan and, particularly, by the MOE, in the early stage of recovery activities of the overall policy, a regulatory framework and strategic approaches, as well as development of various lower-level standards and technical guidance documents for the implementation of waste management activities, including waste treatment, storage, transport and disposal [31, 38, 69]. These technical guidance documents were periodically updated based on gained experience and incorporating best practices.

5.2.1. The overall waste management framework

As described below and presented schematically in Figs. 11 and 12, the overall decontamination waste management framework and strategy included the following main provisions [70]:

- Collection and storage of the decontamination waste in Temporary Storage Sites (TSSs) established near the points of the origin of the waste (basic approach);
- In the populated municipalities, where it was comparatively difficult to find suitable large sites for TSSs, there were a lot of cases in which waste has been stored immediately on the decontaminated site (e.g. in below-ground storages in parks, at residencies, schools, etc.);
- Volume reduction of combustible materials in available municipal and specially constructed solid waste incinerators equipped with off-gas cleaning systems; application of other waste volume reduction techniques (crushing, chopping, compressing etc.);
- Establishing the ISF in the Fukushima Prefecture (for the waste generated in this prefecture) and transportation of decontamination waste from TSSs to the ISF;
- Depending on radioactive content and category of waste, interim storage of decontamination waste (removed soil) in the ISF or disposal in commonly used or specially designated municipal landfills (see below);
- Recycling of lower activity soil in civil construction and/or similar applications (e.g. shielded by uncontaminated materials) (the specific options for recycling are currently evaluated in a series of pilot projects);
- Final disposal of waste in a specially designed engineered facility outside the Fukushima Prefecture (the pilot projects have also been already started).

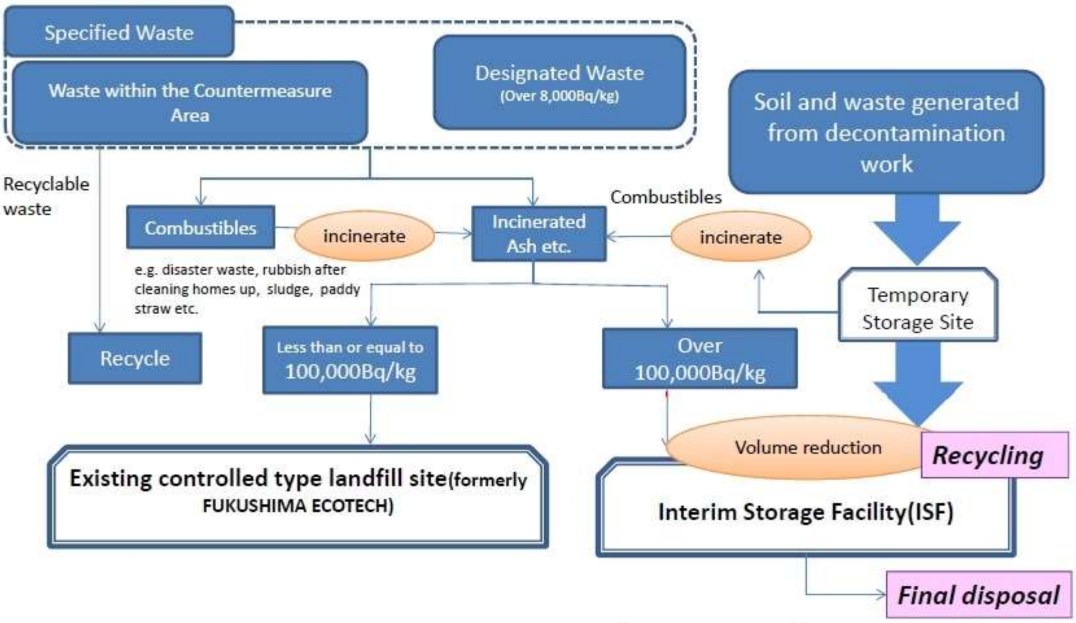


FIG.11. Management of waste generated through decontamination within Fukushima Prefecture based on the Act on Special Measures (reproduced from [70] with permission).

It should be noted that the strategy to manage the contaminated soil which is currently stored in TSSs in prefectures other than Fukushima is still under discussion by Japanese authorities and is yet to be defined.

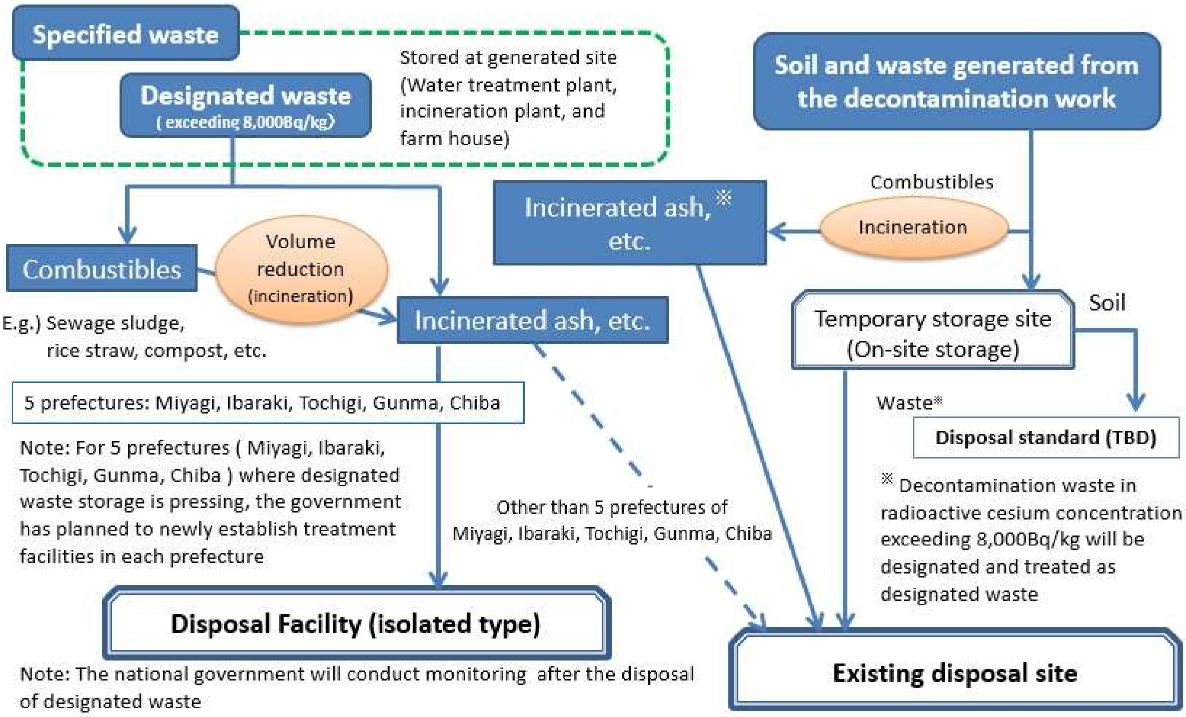


FIG. 12. Management of waste generated through decontamination in prefectures other than Fukushima (reproduced from [70] with permission).

5.2.2. Categorization of waste

The Act on Special Measures Concerning Radioactive Materials provides a categorization of radioactive waste with regard to the following criteria [71]:

- The geographical area where the waste was generated (e.g. the SDA and the ICSA);
- Activity concentration of ^{134}Cs and ^{137}Cs (<8,000 Bq/kg, <100 000 Bq/kg, >100 000 Bq/kg);
- Waste types (combustible, non-combustible waste including the soil);
- Origin of waste (e.g. demolition of houses damaged by the earthquake, radiological clean-up of houses in the evacuated zone, decontamination activities).

In accordance with the above criteria the Act on Special Measures Concerning Radioactive Materials further provides the following definitions of the categories of radioactively contaminated waste within the Fukushima Prefecture:

- Waste within the Countermeasure Area consists of debris from the tsunami, house demolition debris and similar waste resulting from the accident and the subsequent long-term evacuation;
- Designated Waste: this definition applies to waste above the specific activity concentration level of 8,000 Bq.kg^{-1} (such as sewage sludge, incinerated ash, etc.);

- The waste originated in the Countermeasure Area and designated waste is referred to as 'Specified Waste';
- The waste arising from the decontamination activities: soil, vegetation remnants, leaves, litter layer, surface sediments, etc;
- Low-level contaminated waste other than specified waste or the waste originated from decontamination activities: Waste with activity less than or equal to 8,000 Bq/kg. This waste is managed in accordance with the Waste Management and Public Cleansing Act [72].

5.2.3. Roles and responsibilities of central and local authorities in waste management

In accordance with the Act on Special Measures Concerning Radioactive Materials [33], the management and disposal of waste generated during decontamination within the SDA as well as the Designated Waste (irrespective of its origin) are within the responsibility of the national Government, and specifically of the MOE. Management of waste within the ICSA that has radionuclide activity concentrations below the level for the Designated Waste (including storage, volume reduction and disposal) is the responsibility of the local authorities (municipalities) in the ICSA with the oversight and support of the MOE.

5.2.4. Disposal routes for different categories of waste

The radionuclide content threshold allowing for disposal of most of the waste other than the Specified Waste to the municipal landfills is 8,000 Bq/kg.

The Specified Waste in the Fukushima Prefecture with radionuclide activity concentrations between 8,000 and 100 000 Bq/kg has to be disposed of in designated landfills equipped with radiation monitoring and leachate treatment system to control radioactivity releases to the environment.

Waste generated during decontamination works in the SDA and the ICSA are first collected and stored in TSS (following the preliminary necessary storage immediately at the decontaminated site), and then transported to the ISF for treatment operations (sorting, volume reduction) and storage. The Specified Waste with activity concentration > 100 000 Bq/kg (such as incineration ash) is also collected and stored in the ISF in specially designed concrete storage facilities.

The waste management strategy envisages the possibility for recycling of significant part of the lower activity concentration soil stored in the ISF in civil construction projects (ensuring proper shielding by clean materials).

Soil and other waste arising from the decontamination activities and waste with an activity concentration of > 100 000 Bq/kg have to be disposed of in the specially designed engineered disposal facility ensuring an adequate level of long-term radiation protection and safety in the final disposal site to be constructed outside the Fukushima Prefecture.

5.2.5. Amounts of decontamination waste

Estimates of the volumes of different types of decontamination waste in the Fukushima Prefecture regarding specific activity based on preliminary estimations by the MOE are shown in Fig. 13 (assuming the total volume of removed waste in Fukushima Prefecture was at the maximum of 16 to 22 million m^3 as of July 2013). The actual volume arising from decontamination activities in the Fukushima Prefecture was approx. 16.7 million m^3 as of March 2020 [73] and this figure will change over time, for example due to further progress of the volume reduction of removed waste and the construction of the SRRB.

The decontamination activities that were implemented in 2013–2019 in residential and agricultural areas in the ICSA and the SDA in the Fukushima Prefecture covered a surface area of about 9,000 km^2 and produced in total about 17 million m^3 of waste. Based on information from the MOE [70] the volume of decontamination waste produced in the SDA was 9,1 million m^3, and in the ICSA it was 7,9 million m^3.

The decontamination waste is represented mostly by removed soil, and to a lesser extent by plant remnants, rubble, and other materials.

Of about 1,55 million m^3 of waste transported to the ISF by the end of October 2018, soil amounted to 92.4%, combustible materials 5.8% and incineration ash 1.3%. This waste was represented mostly by low activity concentration materials. More than 82.8% of the described waste streams has a specific activity below 8,000 Bq/kg (as estimated based on dose rate and activity measurements at the time of transport from TSS) [74, 75].

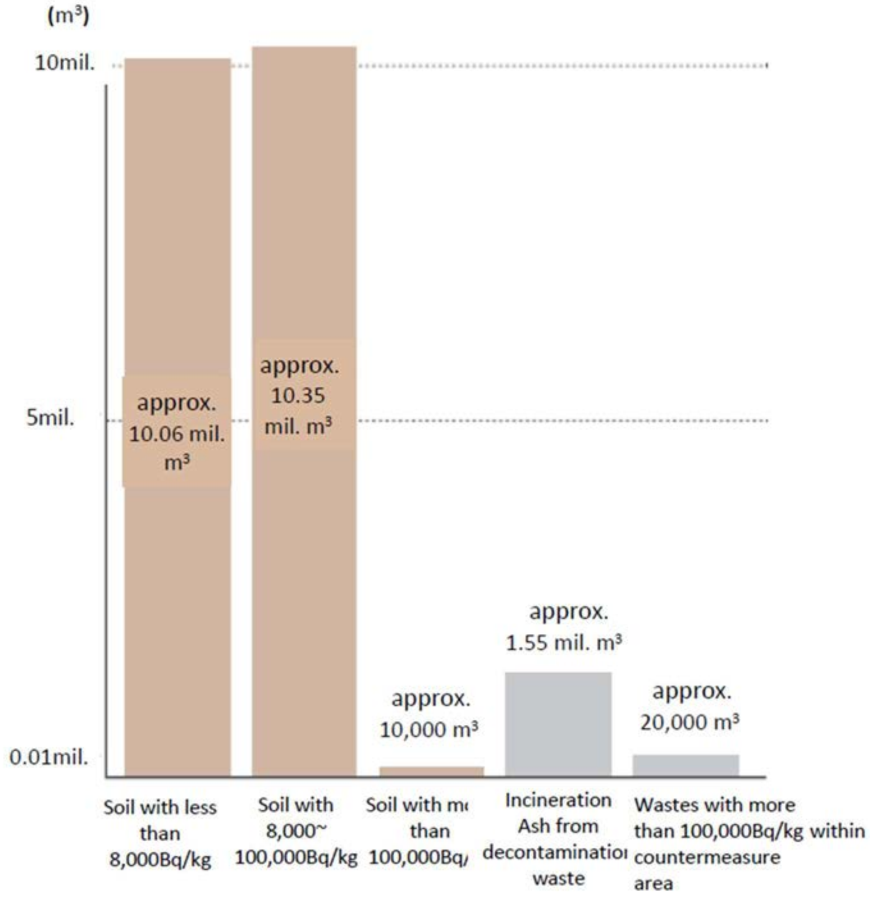


FIG. 13. Preliminary forecast of the quantity of removed waste generated during decontamination works in Fukushima Prefecture regarding different activity threshold levels (reproduced from [71] with permission).

5.2.6. Timeline for decontamination waste management

Waste transportation from TSS to separate stockyards within the area secured for the ISF in Futaba and Okuma Towns started in 2015. The first commissioned soil storage facility started to receive soil from TSS in October 2017. The total volume of waste transported to the ISF by 18 February 2021 was 10.4 million m^3 [74].

According to the current provisions, almost all the decontamination waste, excluding that from the DRZ, is planned to be transported from TSSs to the ISF by the end of the 2021 fiscal year.

The final disposal of waste from the ISF is intended to take place within 30 years from its start of operation (i.e. by 2045). The final disposal facility has to be constructed outside the Fukushima Prefecture.

The subsequent sections provide additional details on how this strategy has been implemented and share acquired experiences and lessons learned.

5.3. WASTE TREATMENT EXPERIENCES AND CHALLENGES

The extremely large amounts of wastes that have been generated with the remediation work imposed the adoption of different approaches to reduce their volume and consequently facilitate the management of these materials. Below, are some examples of approaches that were punt in place in Japan.

5.3.1. On-site waste volume reduction for storage in temporary storage sites (TSSs)

The need for on-site reduction of the volume of decontamination waste for subsequent storage in TSSs was an important issue because of the limitation of locations available for storage. The relevant techniques used in the course of decontamination works before putting waste into containers (big bags) included [71]:

- Crushing: this method was applied to branches originating from decontamination of forests. Branches were crushed using a crusher and were packed in big bags to reduce the air space;
- Chipping: this technique was applied to branches and leaves to reduce them to the size of chips using self-propelled wood chippers;
- Crushed and/or chipped waste on some occasions was further reduced in volume using the application of vacuum compression and compression bags for storage. This method can reduce organic materials such as branches, leaves, grass etc. to one-half to one-third of the original volume.

Examples of the application of the listed above techniques can be found in Ref. [71].

5.3.2. Volume reduction of combustible waste

The MOE carried out a programme to reduce the volume and stabilize properties of Designated Waste through incineration and drying [76, 77].

The drying technology has been applied to contaminated municipal sewage sludge. This technology was used at a sewage treatment plant in Horikawa Town, and in the Fukushima Prefecture Central Purification Center (at Koriyama City). Both facilities operated between 2014 and 2016.

It was decided by the MOE to incinerate inflammable waste to reduce waste volume at TIFs to be constructed in multiple locations to cover the needs of neighbouring municipalities in the Fukushima Prefecture (see Fig. 14). This includes incineration facilities constructed at the ISF site in the Okuma and Futaba Towns to treat waste transported to the ISF. As of January 2018, seven such facilities were in operation and were processing the waste, although some of them have since been demolished as originally planned [76].

The TIF in the Iitate Village (Warabidaira District) was processing contaminated waste generated in the Iitate Village and five surrounding municipalities. It started operations in January 2016. The plant processed not only waste from decontamination work and scrap from dismantled houses in the Iitate Village, but also rice straw and pasture grass generated in other municipalities i.e., Minamisoma City, Date City, Kunimi Town and Kawamata Town as well as sewage sludge from Fukushima City, Minamisoma City and Kunimi Town. The same site also hosted a demonstration facility to recycle materials such as removed soil or ash from waste incineration. The facility was capable of processing around 10 tons of waste a day.

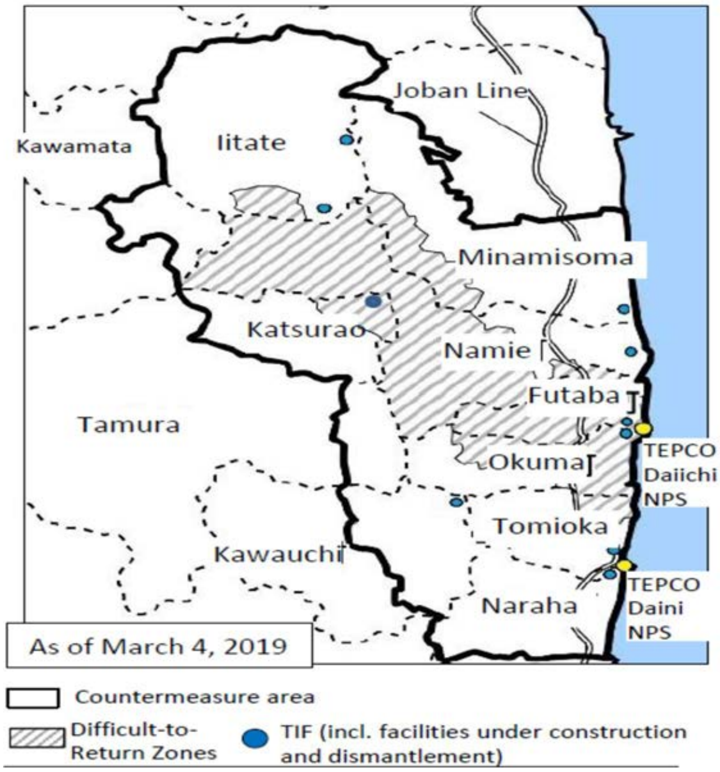


FIG.14. Map showing locations of incinerator facilities for combustible waste in Fukushima prefecture (reproduced from [71] with permission).

The incineration ash contains higher activity concentrations compared to the original waste by a factor of about 30 for fly ash and by a factor of about 4.6 for bottom ash. Incineration ash containing no more than 100 000 Bq/kg of radiocaesium was transported to the landfill site equipped with a seepage control system in Tomioka Town, whereas the ash with concentrations exceeding this value was transported to the ISF for further disposal.

5.3.3. Waste treatment to minimize volumes for final disposal

Treatment of soil and incineration ash containing low levels of activity by volume reduction technology with further recycling of clean material is the principal element of the MOE strategy towards reducing the volume of remediation waste and the Designated Waste for final disposal outside Fukushima Prefecture [78,79]. The volume reduction of radioactively contaminated soil can be achieved by combining various volume reduction techniques, including:

- Classification treatment (to separate the fine fraction of soil such as clay/silt enriched with radiocaesium and to separate soil below or above 8,000 Bq/kg);
- Chemical treatment (to dissolve and separate radiocaesium using, for example, strong acid solvents);
- Heat treatment (to gasify, cool, solidify, and collect radiocaesium evaporated by heating).

The review and collected research on various relevant waste treatment technologies is provided in Refs [80,81]. The conceptual scheme of consecutive application of various volume-reducing technologies to minimize waste volumes for final disposal is shown in Fig. 15.

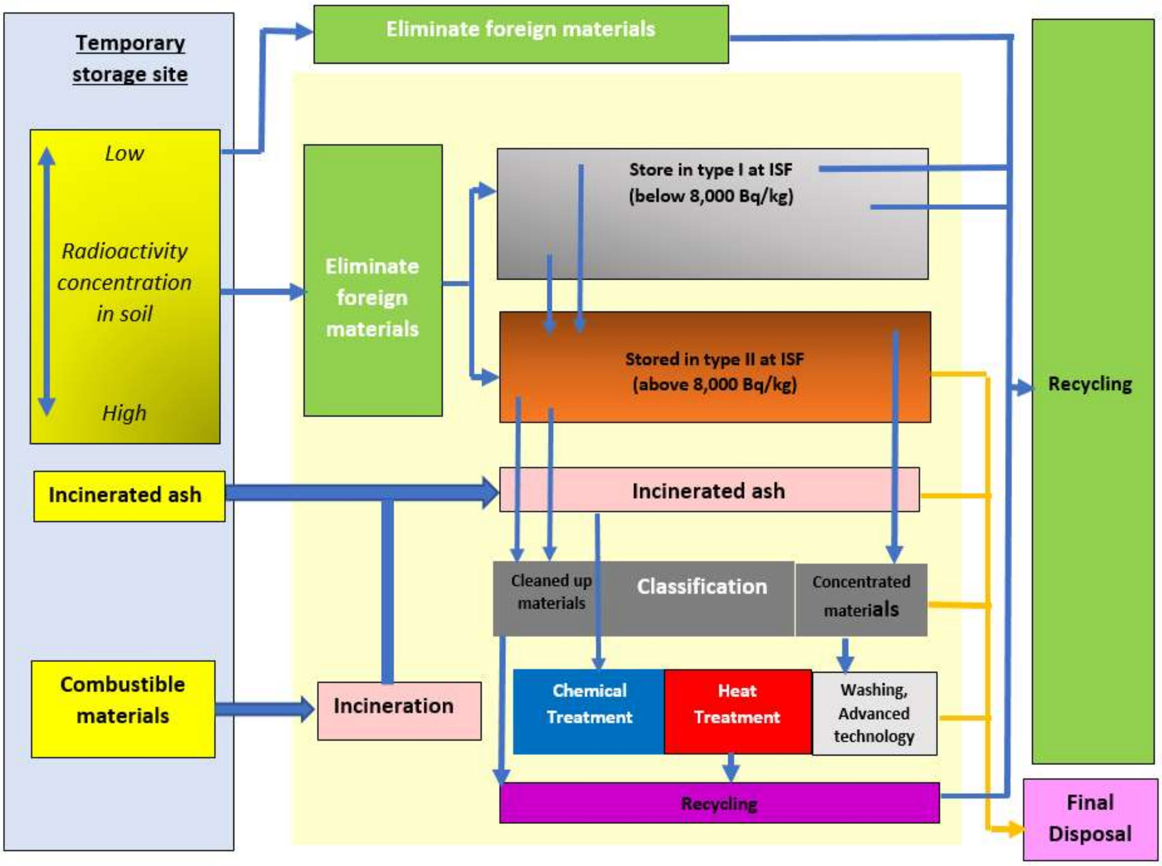


FIG.15. Conceptual block scheme of the application of volume-reducing technologies to minimize waste volumes for final disposal (reproduced from [78] with permission).

The illustrative scenario of the potential impact of volume reduction on the resulting volume of waste for final disposal is shown in Fig. 16, assuming that material containing < 8,000 Bq/kg of radiocaesium can be recycled.

The MOE has not yet taken the decision on waste treatment technologies to be applied and is currently fostering research in this area, including conducting pilot demonstration projects. The current planning allocates 10 years for R&D and pilot applications before deciding on the full-scale application. The decision on selecting potential technologies will incorporate criteria of safety, economic considerations, costs of treatment vs. disposal costs, and public acceptance of various options.

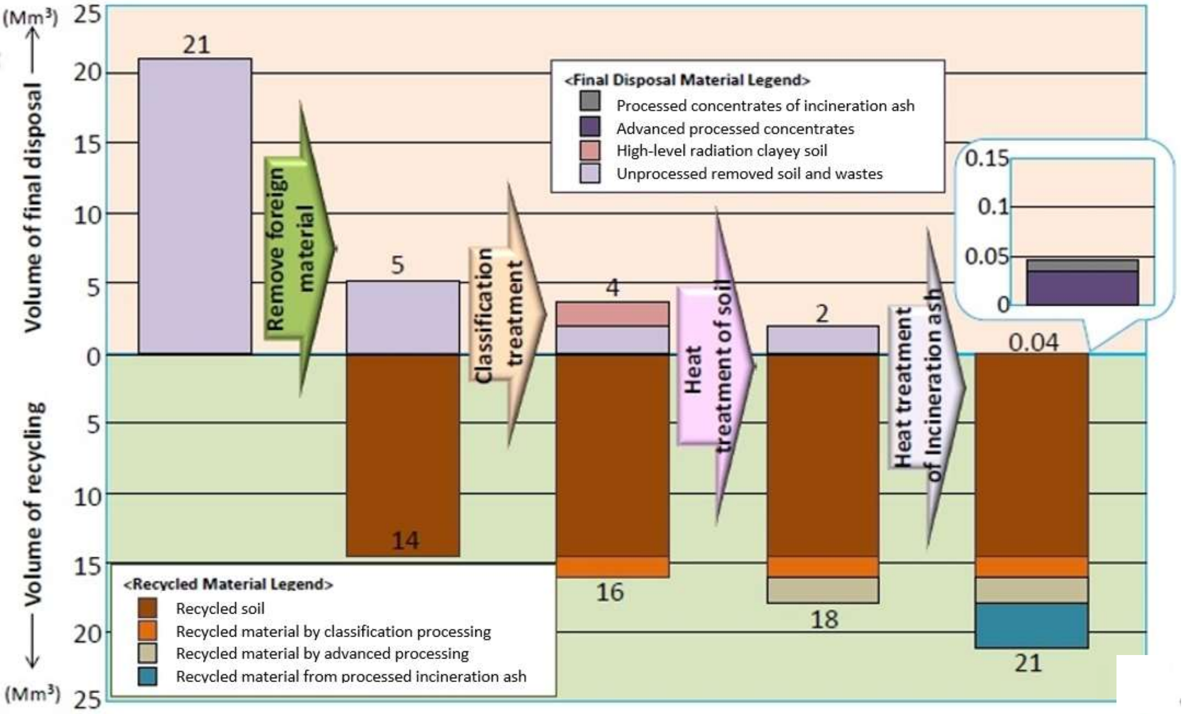


FIG.16. An illustrative scenario of the potential impact of volume reduction technologies on the resulting volume of waste for final disposal (reproduced from [79] with permission).

5.4. EXPERIENCES IN MANAGING TEMPORARY STORAGE SITES

Establishing TSSs was necessary because of the time required for establishing and commissioning of the ISF. Creating TSSs allowed simultaneously implementation of numerous decontamination projects in different prefectures and locations over a short period.

5.4.1. Need for Temporary Storage Sites (TSSs)

Contaminated waste generated from decontamination activities were initially collected and stored at TSSs, situated at or in the close vicinity of the land areas undergoing remediation in each municipality or community. In some municipalities where it was difficult to find a suitable site, waste was temporarily stored at the decontaminated site (e.g. in residences, parks, schools etc.), followed by the transportation to TSS and then to the ISF (after construction). Individual TSSs needed to be placed on flat land with sufficient area for storage of waste and with proper access to roads. In the case of residential areas, sufficient distance of TSSs from the inhabited locations has been secured.

5.4.2. Land acquisition

Securing locations for TSSs and gaining the consent of relevant stakeholders was a prerequisite for starting decontamination works. In the case of the SDA, the sites were selected in consultation with the local municipalities, local communities, and landowners. In the case of the ICSA, consent of the residents in the vicinity of the TSS was also an important prerequisite.

The land acquisition for TSSs has often been a difficult task due to the concerns of landowners. The complexity was increased by logistical constraints as landowners were often evacuated following the accident to distant locations in Japan. As a result, in some instances this had a serious impact on the timely implementation of remedial works. Initially, there was no good understanding by landowners of the purpose, nature and intended time of operation of the TSSs. The associated radiological risks were also a concern. These included: the possibility for elevated dose rates near a TSS, and leakage and dispersion of contamination. Residents were also afraid that TSSs may end up being permanent disposal sites. Therefore, a process of trust-building through communication and discussions of risks was needed (e.g. by explaining shielding of waste by clean soil, providing evidence of successful work from other remediated sites, etc.). Eventually, many landowners have provided their land for TSS because the understanding of issues has been achieved and they wanted to contribute to the success of remediation and revitalization efforts by Government and local authorities.

In several cases in the ICSA, particularly in the densely populated areas, such as Fukushima City, and Koriyama City it was difficult to find spacious enough candidate sites for TSS, and decontamination proceeded by locally storing the removed soil in the place where waste was generated (such as house yards, public parks, etc.).

5.4.3. Temporary Storage Site (TSS) design and maintenance

The technical guidelines for the design and implementation of TSSs were provided by the MOE [39]. These guidelines have undergone several revisions and updates based on the experience acquired during decontamination work.

Contaminated materials generated during decontamination works were collected and stored in TSSs in different types of large flexible bags of about 1 m^3 capacity, such as cross-shape flexible containers, running type (multiple uses) flexible containers, and heavy weather-resistant large container bags with inner bags. When filling these containers, waste was sorted and the containers were tagged to mark different waste categories, such as: soil, gravel pebbles, etc.; decomposable combustibles (vegetation remnants etc.); combustible materials (cloths, suits, masks etc.); non-combustible materials (concrete rubble, asphalt etc.); and hazardous materials (asbestos-containing waste etc.). With the progress of decontamination work, hand-written labels were replaced by QR-codes. The dose rate at the surface (1 cm distance) of the containers into which the waste material has been placed was also measured and recorded.

TSSs have several varieties of design depending on the type of waste and local storage conditions. The schematic design of a TSS for incombustible waste materials is shown in Fig. 17.

The containers with clean soil were used for shielding in order to ensure that the gamma dose at the site boundary did not exceed the levels of the surrounding territory. The waste was isolated from the bottom and top by impermeable cover sheets to prevent rainwater ingress and leakage.

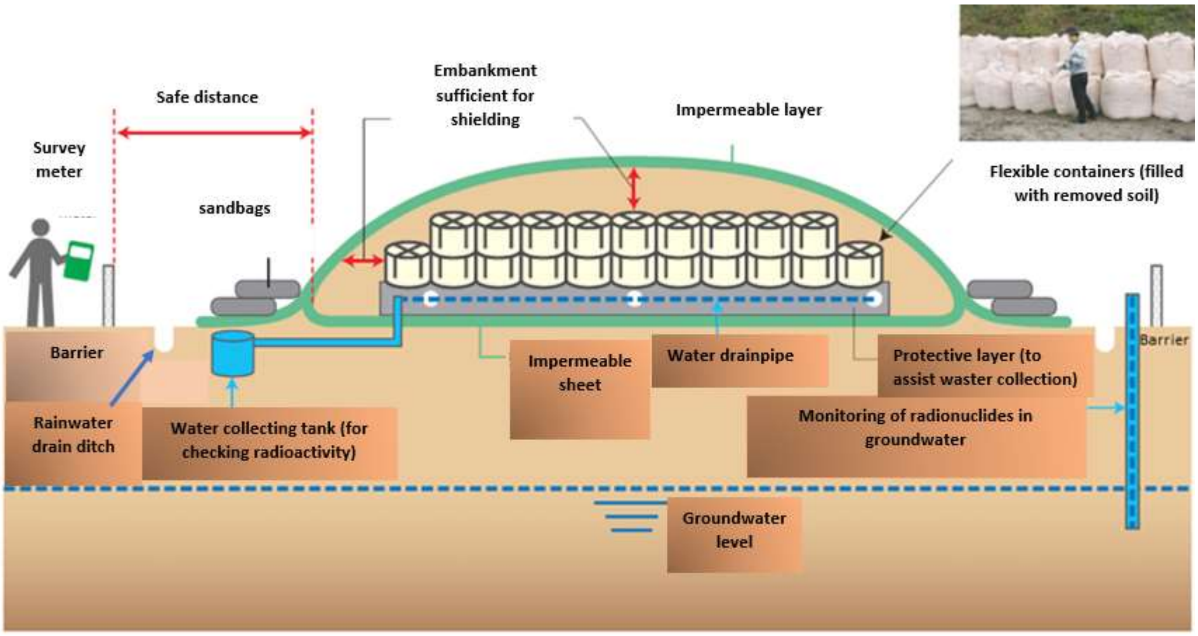


FIG. 17. Schematic design of TSS for the incombustible waste (reproduced from [82] with permission).

At the early stage of the decontamination projects, it was often not possible to use waterproof containers to store the removed waste. Because of that, the TSS design considered the possibility for bottom drainage, either by means of gravity flow or by means of pumping [82]. The drainage water was then collected in a facility, such as a storage reservoir or tank (see Fig. 1). The drainage water was monitored for radioactivity and treated (as needed) to ensure that the relevant releases criteria were met. Based on the experience accumulated with the management of TSSs, the container bags, filled with uncontaminated sand, have been piled up surrounding the contaminated waste. When waterproof containers were made available the water collection tanks became redundant.

The TSS designs for combustible materials (removed vegetation, etc.) foresaw establishing a venting system (degassing pipes). They also contemplated the operation of temperature sensors and the use of ventilation pipes and/or “breathable waterproof sheets” covering the top of the TSSs. Such a design was implemented to avoid the possibility of heat building up in the system and the occurrence of over-pressurization by gases generated by the biodegradation of organic materials present in the wastes. Additional details on TSS design can be found in Refs [38, 70].

During waste storage, TSSs have undergone periodical inspections and checks to ensure proper isolation of waste. These checks were carried out in the SDA by the MOE contractors in accordance with the technical guidance documents prepared by the MOE. In the ICSA these checks were performed by the municipalities' contractors. The TSS checks include visual inspections and air dose rate measurements (at a weekly frequency); groundwater activity checks (monthly); checking of presence and activity concentration of water in drainage collection tanks (with the eventual treatment of the drainage to remove reduce activity concentration as needed). Additional inspections were completed following extreme weather conditions (e.g. heavy rain, typhoon, earthquake). If needed, TSS maintenance measures (removal of pooling water from the upper surface of impermeable cover sheets; removal of weeds growing on top of bags etc.) and repairs (e.g. shaping top cover to prevent cratering of water on top cover) and additional isolation measures were implemented.

5.4.4. Number of Temporary Storage Sites (TSSs) and quantities of waste

In total, 330 TSSs were constructed by the end of December 2020 in the SDA. The total number of bags with waste was about 10.35 million as of December 2020 (the volume of each bag was about 1 m^3).

In total 1,041 TSS were constructed by the end of December 2020 in the ICSA in the Fukushima Prefecture. The total number of generated bags with waste reached about 6.86 million m^3 (as of December 2020). In the ICSA in the Fukushima Prefecture, waste was stored in a total of 190 thousand on-site storage sites and the number has plummeted according to the progress of the transportation to the ISF.

5.4.5. Temporary Storage Site restoration upon completion of waste storage

Once the transportation of waste from TSSs to the ISF started in 2015, the important issue became site clean-up and restoration of the TSSs to original conditions following removal of waste. The respective procedures have been developed by the MOE and by the Fukushima Prefecture and incorporated into the technical guidance documents on lifecycle management of TSSs [83].

According to the waste management policy and legal agreements with the TSS landowners, land used to host the TSSs should be restored to its original state after TSS dismantling. The restoration plans should account for landowners' will and land utilization plans.

A flow chart of procedures and operations for TSS land restoration to its original state is shown in Fig. 18. The site restoration operations included removal and proper disposal of TSS constructions (such as fences, bottom impermeable sheets, basement materials and access road materials, etc.). The procedures also fostered the reuse of ‘clean materials’ (e.g. from shielding containers) following the restoration of TSSs. Returning TSSs to agricultural use could include restoration of soil properties by proper levelling, application of fertilizers, ploughing, and installation of drainage systems for paddy fields. Upon completion of site restoration works, potential residual contamination of land is checked by measuring air dose rates and radionuclide activity concentrations in soil. These measurements were checked against the background values measured before TSS was constructed.

In the wake of the progress of the transportation to the ISF and the establishment of the specific procedures for the restoration of TSSs, in the SDA, 128 of 330 TSSs were restored and returned to the landowners as of December 2020. In the ICSA in the Fukushima Prefecture, 541 of 1,041 TSSs were restored and returned to the landowners as of December 2020.

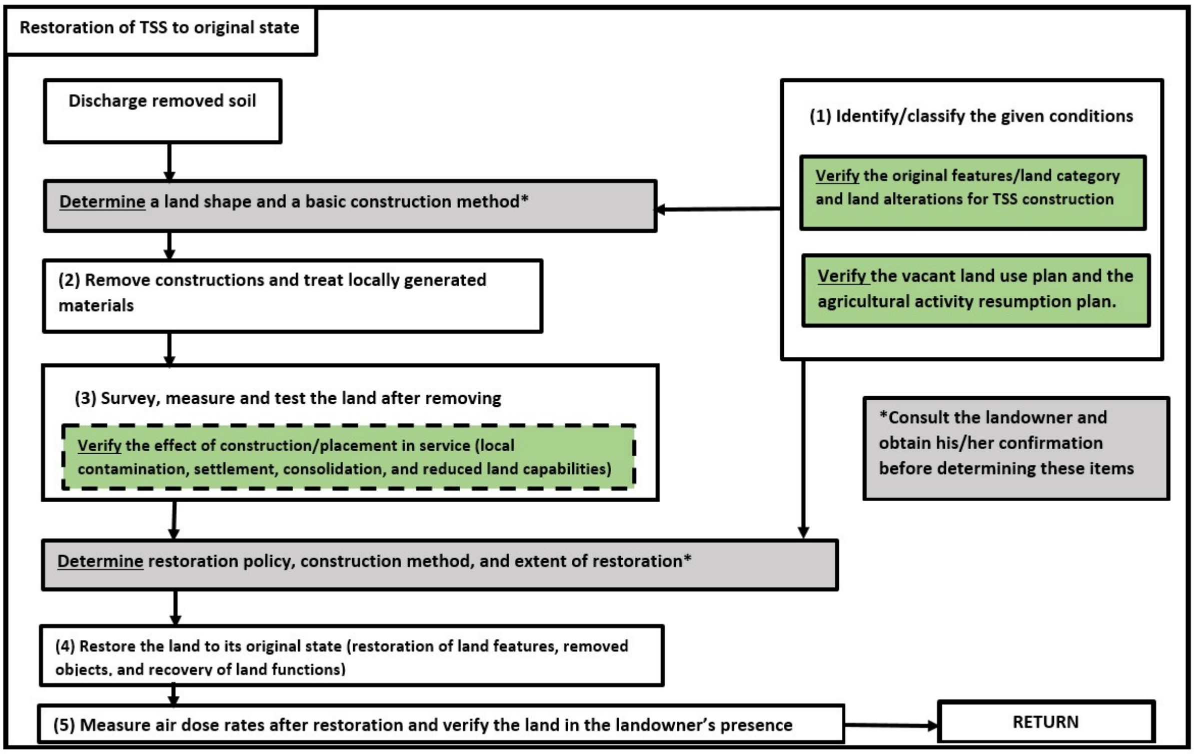


FIG. 18. Flow chart of TSS land restoration to its original state (reproduced from [83] with permission).

An example of TSS restoration work is given in Fig. 19. The progress of work on TSS restoration [84] is illustrated in Fig. 20.

(A) Waste storage at the TSS site *(B) Site area after restoration is completed*

FIG. 19. Photographs of a TSS in the Tamura City during waste storage and following site restoration (reproduced from [31] with permission).

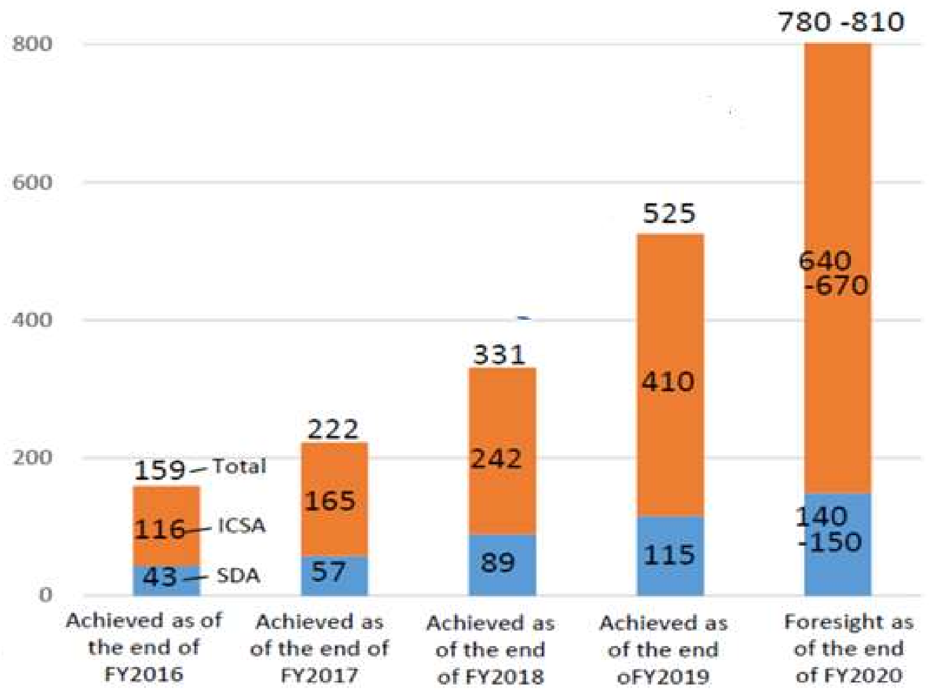


FIG. 20. Progress in the restoration of TSS for 2020 estimates (reproduced from [84] with permission).

5.5. THE INTERIM STORAGE FACILITY

The main objective of the ISF is to ensure predisposal treatment and safe storage of radioactively contaminated waste generated during decontamination works in the Fukushima Prefecture until a final disposal site is available. The site selection, construction, and management of the ISF are within the responsibility of the national government of Japan. The ISF facility is designed exclusively for waste originating within the Fukushima Prefecture.

5.5.1. Site selection and approval by local authorities

The site selection process for the ISF by the MOE has started in 2013 and considered the following criteria:

- Existence of sufficient area for waste storage and operation of auxiliary facilities;
- Proximity to areas that generate decontamination waste to be stored;
- Availability of highways to access the site instead of ordinary community roads.

The decision making about the siting of the ISF was concluded by 2014. The decision was to establish the ISF in Okuma Town and Futaba Town near the Fukushima Daiichi NPP site. The approval of the ISF site by local authorities and landowners was a challenging process requiring intensive negotiations with provisions of guarantees by the national government.

The Fukushima Prefecture approved the construction of the ISF upon confirmation by the national government of five principles:

- Enactment of the law for the final disposal of waste outside the Fukushima Prefecture;
- Provision of a budget for establishing and operation of the ISF;

- Clarification of operation and maintenance of waste transportation routes;
- Ensuring the safety of the facility and waste transportation;
- Safety agreement with the Fukushima Prefecture, Okuma Town and Futaba Town.

The main stages of planning, negotiating, establishing and starting the operation of the ISF are summarized in Table 7 [85].

TABLE 7. BACKGROUND AND HISTORY OF THE INTERIM STORAGE FACILITY (reproduced from with permission from MOE)

Date	Events related to establishing the ISF
Oct. 2011	The MOE announce the basic policy and roadmap regarding establishing the ISF.
Dec. 2013	The MOE requested that the Fukushima Prefecture and the 3 Towns (Futaba, Okuma and Naraha) accept the establishment of the ISF.
Feb. 2014	The Governor of Fukushima requested the national government to consolidate the ISF in the Okuma and the Futaba.
Sep. 2014	The Fukushima Prefecture approved the construction of the ISF asking the government to confirm 5 principles.
Nov. 2014	The amendment bill for the JESCO Law in order to legislate the final disposal of contaminated soil and waste outside the Fukushima Prefecture was approved by the Cabinet and put into effect in December.
Dec.2014−Jan.2015	Both the Okuma and the Futaba accepted the construction of the ISF.
Feb. 2015	The construction of stockyards in the ISF started. The Governor of Fukushima and both mayors of the Okuma and the Futaba allowed transportation of waste to the ISF.
Mar. 2015	Transportation of soil from TSS to the stockyards started in Okuma on 13 March, and in Futaba on 25 March.
Mar. 2016	The MOE compiled the operating plan for waste transportation to the ISF. Ad-hoc Five-Year Plan for the ISF announced.
Nov. 2016	Construction of the Soil Separation Facility and the Soil Storage Facility started.
Oct. 2017	The Soil Storage Facility started its operation.
Jan. 2019	The ISF Information Centre opened.

The total ISF site area is approximately 16 km^2 (1.600 ha). About 21% of this land is national or municipality-owned land, while the rest was privately owned land, which required placing by the government of land lease contracts with the landowners. About 1,205 ha of land for the ISF has been contracted by the government as of January 2021 which required placing contracts with 1,787 individual landowners.

5.5.2. Waste treatment and storage facilities

The waste stored in TSSs to be disposed of in the ISF is mostly represented by a very large volume of soil containing low levels of contamination, together with a relatively small amount of other materials (vegetation remnants, stones etc.). This soil can be considered as a valuable resource that can be potentially recycled following sufficient radioactive decay of caesium radioisotopes and/or taking appropriate precautions that the reused soil is shielded by non-contaminated materials.

Therefore, the development of the waste soil treatment strategy and concept for the ISF required the development of unique specially tailored approaches and technologies that have not been previously applied in the nuclear waste management sector. This waste soil treatment and storage technology is briefly outlined below.

The flow chart of waste treatment at the ISF is shown in Fig. 21.*FIG. 21*

The layout of various facilities on the terrain is shown in Fig. 21 The ISF comprises a complex of waste and soil stockyards for transported waste, waste treatment plants (soil separation, combustible waste incineration), and waste storage facilities (for soil, and incinerator ash), as well as auxiliary facilities (administrative offices, etc.).

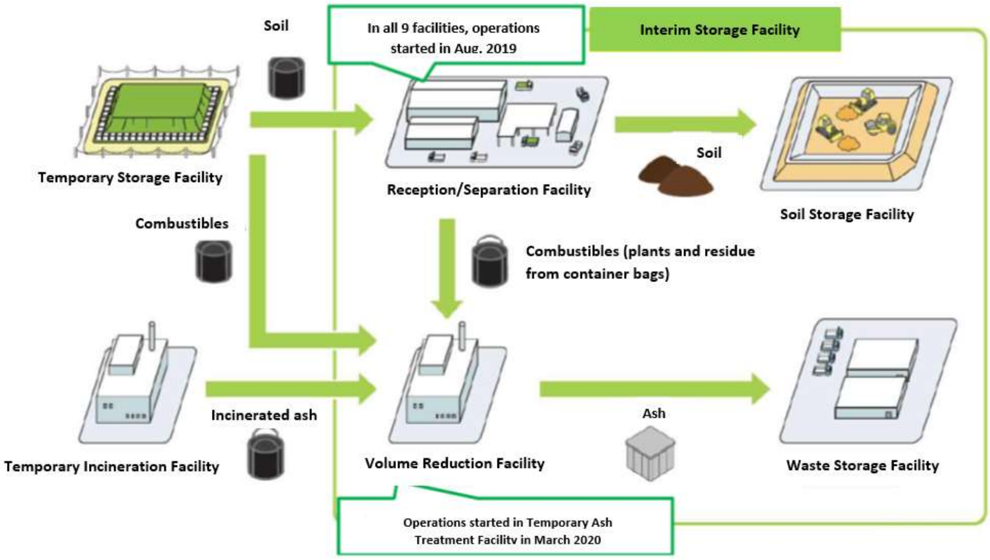


FIG. 21. Flow chart of radioactive material treatment and storage operations at the ISF (reproduced from [31] with permission)

The flexible containers of waste are mechanically processed at a conveyor where the containers are opened and the waste is passed through sieving machines that separate soil from larger objects (stone, metal etc.) and combustible materials (containers remnants, plant residues etc.). The combustible materials are directed to the incinerator facility. The separated soil is directed to the Soil Storage Facility. Initial treatment of waste arriving from TSS is carried out at the Soil Separation Facility (Fig. 22a).

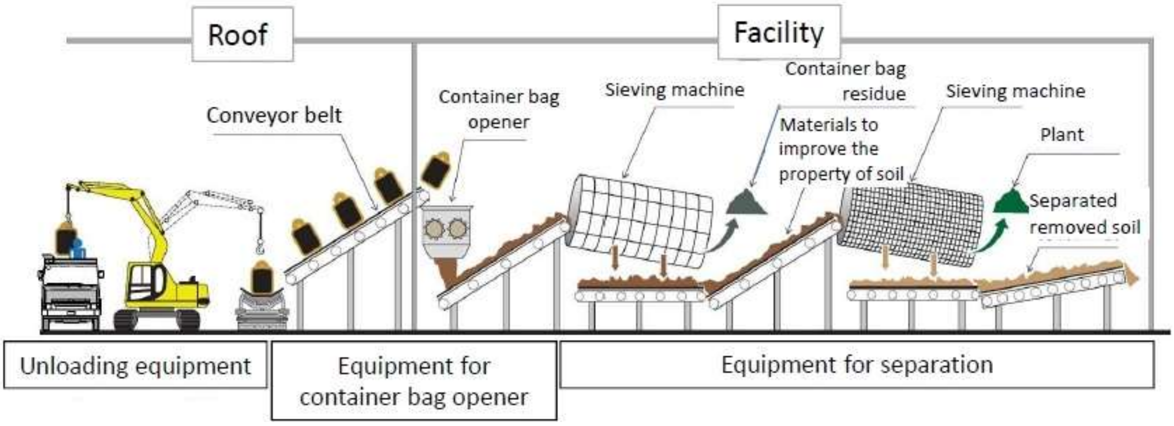
Transportation of soil that has passed from the Soil Separation Facility to the Soil Storage Facility is carried out using trucks or conveyor belts (Fig. 22b). The Soil Storage Facility is a landfill facility with double liners and a drainage water collection system at the bottom and along the enclosing dikes. The arriving soil is levelled and compacted by bulldozer equipment. The drainage (leachate) water is collected and directed to the leachate control and treatment facility. Upon completion, the landfill will be covered by a soil cover incorporating impermeable liners.

The ash produced by the incinerator and ash treatment plant is directed to storage in steel containers in the above-ground interim storage facility constructed from the reinforced concrete.

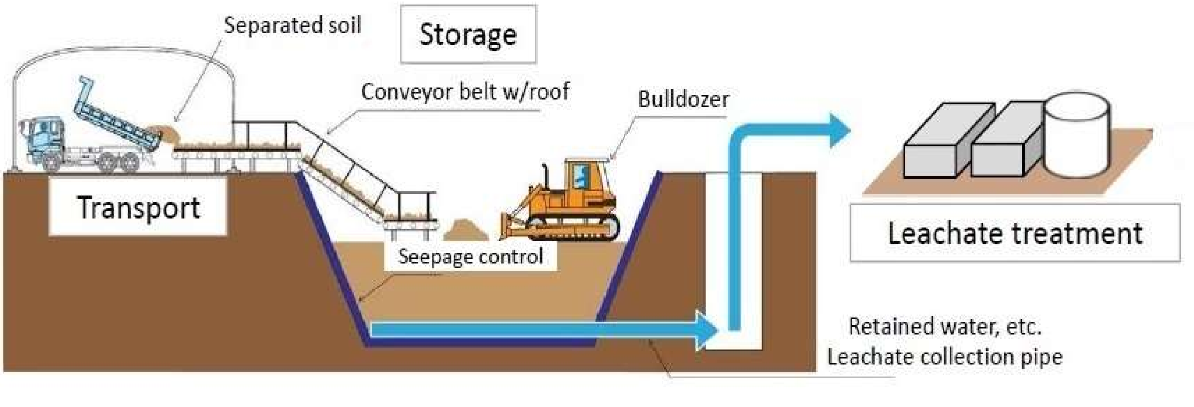
The waste treatment and storage facilities are equipped with radiation monitoring systems including dose rate measurements, exhaust air quality control, and groundwater monitoring.

Various auxiliary facilities include entry and exit gates equipped with relevant checking equipment; stockyards for storage of waste awaiting processing; vehicle waiting area (accommodating vehicle with arriving waste waiting for discharge); screening facility for checking contamination of outgoing vehicles; security guard station; analytical facility for soil and water samples generated at the site; and technology test site (for R&D activities on waste treatment and volume reduction).

The Interim Storage Facilities Information Center (ISFIC) opened along the major road with convenient accessibility, in the vicinity of the site in January 2019. The ISFIC provides visitors with information on the progress of transportation, treatment, and storage of decontamination waste at the ISF, and on the relevant safety measures and aspects.



(a) Soil separation facility



(b) Soil storage facility

FIG. 22. Conceptual schemes of the soil treatment and storage facilities at the ISF (reproduced from [82] with permission).

5.5.3. Status of waste transport, treatment, and storage operations

The target volume of waste soil to be transported from TSSs to the ISF is 14 million m^3 (this number does not include the volume of incineration waste (over 100 000 $Bq.kg^{-1}$) or the wastes that may be produced by decontamination works in the DRZ).

A cumulative total volume of approximately 10.46 million m^3 of waste has been transported from TSSs to the ISF (as of February 18, 2021), which represents approx. 75% of the target. The above-mentioned volume includes both processed wastes and waste awaiting treatment in stockyards. An aerial view of the soil storage operation at the ISF is given in Fig. 23.

Data on type and radioactivity characteristics of waste transported to the ISF by October 2018 (1.55 million m^3) are shown in Fig. 23. Most of the waste material (>92%) is soil. Approximately 83% of this waste had activity concentrations below 8,000 $Bq.kg^{-1}$ (the activity concentration criterion for Designated Waste); nearly 60% of that amount was less than 3,000 $Bq.kg^{-1}$.

FIG. 23. An aerial view of the part of the ISF – Soil storage facility in the Okuma Section as of 14 February 2020 (reproduced from [31] with permission).

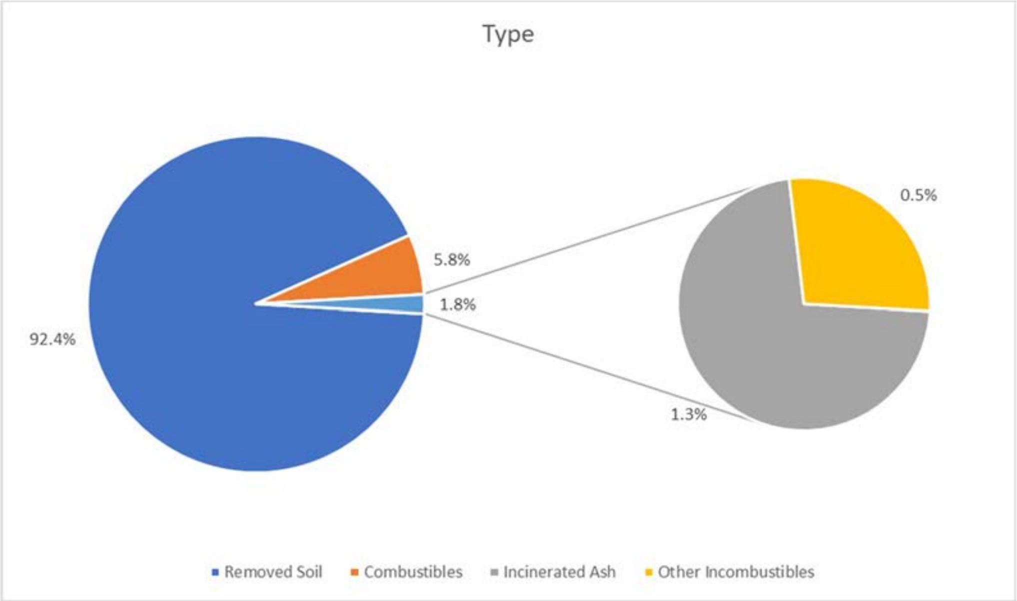


FIG. 24. Distribution of waste transported to the ISF per type in soil by Oct. 2018 (reproduced from [86] with permission).

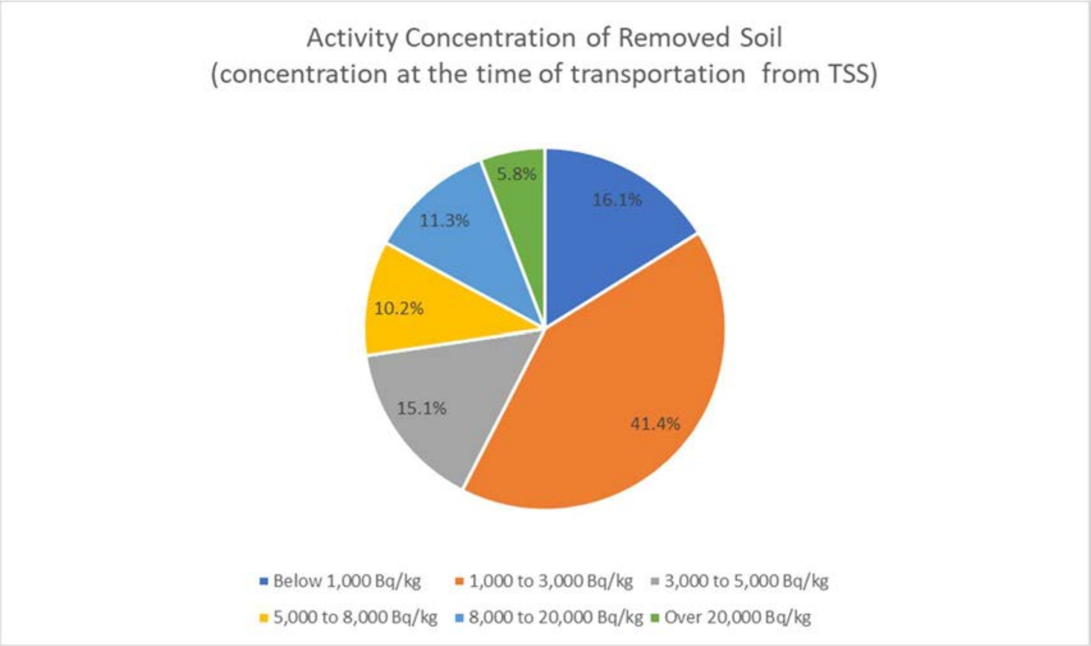


FIG. 25. Distribution of waste transported to the ISF per activity concentration in soil by Oct. 2018 (reproduced from [86] with permission).

5.6. WASTE TRANSPORTATION ISSUES AND EXPERIENCES

The transportation of waste from TSSs to the ISF is a sensitive issue, due to concerns from the public and local authorities that large scale transportation operations may cause traffic jams, may result in (radiological) accidents and may cause elevated radiation exposure from passing vehicles transporting waste. Therefore, waste transportation routes from TSSs and other transport provisions were discussed and agreed upon on a comprehensive and transparent basis with the interested parties as an integral part of an agreement on establishing the ISF in the Okuma Town and the Futaba Town (see the previous section).

5.6.1. Principles for transporting waste from Temporary Storage Site to the Internal Storage Facility

The basic principles of the MOE for transporting removed waste from TSSs to the ISF encompassed:

- Transportation of radioactive materials in a safe and secured manner;
- Transfer of waste from TSSs to the ISF as soon as possible;
- Maintain understanding and cooperation on waste transportation related issues with the public, local authorities and other relevant interested parties.

Waste transportation operations from TSSs to the ISF follow plans developed by the MOE and were carried out in accordance with the relevant detailed technical guidance documents [39,69].

Prior to full-scale transportation, the MOE implemented, for about a year (starting from 2015), pilot transportation tests. During pilot transportations, approximately 1,000 m^3 of removed soil was moved from each relevant municipality, with account being taken of each specific situation regarding waste storage, access routes to the ISF, etc. During pilot transportations, the MOE conducted, in an integrated manner, management of transported materials, traffic management (transportation vehicles) and monitoring aimed at ensuring transportation in a safe and smooth way.

5.6.2. Waste transport from Temporary Storage Sites to the Internal Storage Facility

The waste transportation operations from TSSs employ 10-ton dump trucks. The waste from TSSs is transported in large bags, and the truckload is covered by a protective sheet to prevent possible dispersion during transport (see Fig. 26).

FIG. 26. Truck with waste covered by a protective sheet (reproduced from [31] with permission

The transportation process is controlled by the Transportation Management Center operated by JESCO. This centre monitors the driving situation on routes and provides real-time tracking of each moving vehicle using GPS and telecommunication means. The waste transportation routes are carefully planned to avoid traffic jams during commuting hours. Routes are also selected to avoid as much as possible residential streets, commercial streets, routes that pass by schools so that impact on regional residents can be avoided but also trying to provide resting and waiting areas for truck drivers.

The unprecedented scale of waste transportation operations to the ISF can be appreciated if it is considered that around 2,500 transportation operations from TSSs to the ISF took place daily in 2019 [86].

The transportation routes were equipped with monitoring stations for air dose rate, noise, vibration, and air quality (see Fig. 27). Monitoring information is provided on the electronic screens along the waste transportation routes and the website for interested parties and general public information. Based on transportation experience between March 2018 and February 2019 the air dose rate from passing vehicles at sideway did not exceed 0.3 μSv.h^{-1}.

FIG. 27. Dose rate monitoring station for waste transportation (reproduced from [86] with permission).

According to the plans of the MOE on the preparation of this publication, the transportation of wastes (mainly contaminated soils from Fukushima Prefecture) to the ISF was expected to be concluded by the end of the 2021 fiscal year (excluding the waste generated in the DRZ) (see Fig. 28).

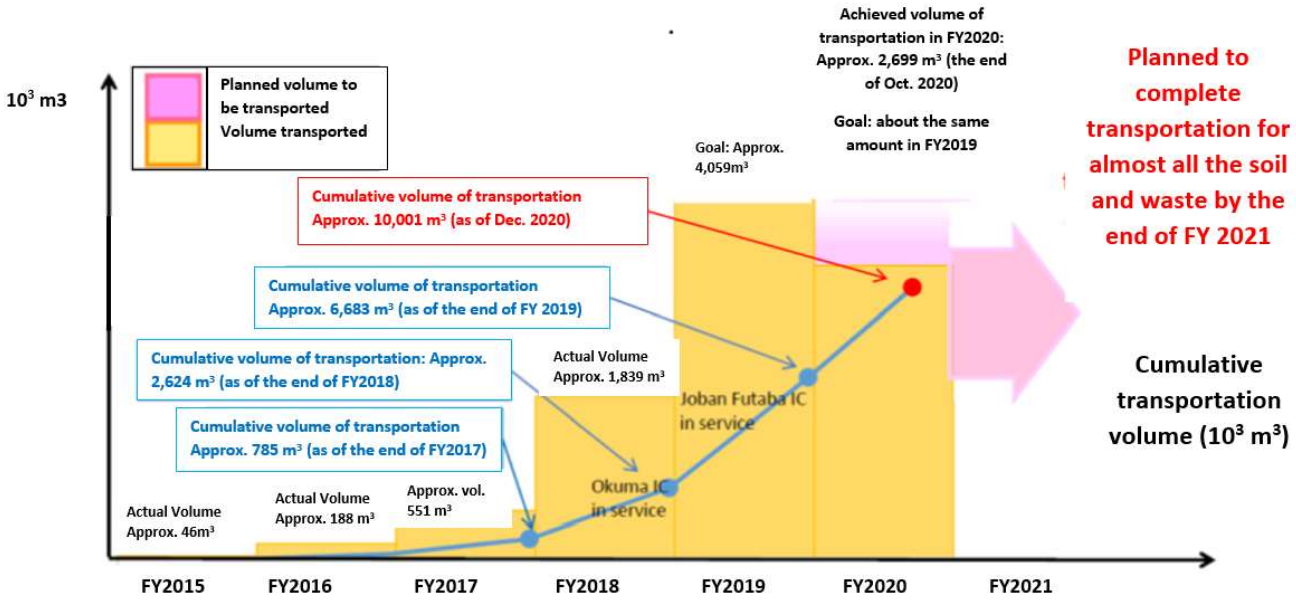


FIG. 28. Transported volumes of waste from Temporary Storage Facilities as of December 2020

5.7. APPROACHES AND ISSUES IN SOIL RECYCLING

As already mentioned, the decontamination waste is represented to a large extent by soil containing relatively low levels of contamination (see Section 5.2.5). Therefore, because of the very large amount of soil accumulated for storage in the ISF, the MOE is seeking approaches for minimizing as much as possible the volume of waste requiring storage and final disposal by utilizing recycling.

5.7.1. Basic concepts for soil recycling

The ‘Basic concept concerning the safe use of recycled removed soil’ was presented by the MOE in Jun. 2016. The basic principles to be followed during soil recycling are [79,80]:

- Ensuring radiation safety of soil recycling;
- Testing recycling technologies through demonstration projects;
- Building confidence and trust in the technology for recycling radioactively contaminated materials with the public and other interested parties;
- Proper keeping of records.

Other elements of the strategy include preparation and publication of a guidance document on proper use and management of the recycled soil (including necessary precaution and safety aspects) and developing and promoting the policy for soil recycling (including social and economic incentives).

According to current planning by the MOE, appropriate soil recycling approaches, technologies and management systems will be developed and tested, followed by a full-scale application.

5.7.2. Options for soil recycling

The current approach foresees the recycling of contaminated material in public civil construction projects with a clearly defined entity responsible for the safe management and surveying of the respective structures incorporating materials with low levels of contamination.

The structures constructed using recycled soil are not supposed to be subject to artificial interferences (e.g. soil works, changing shape, etc.) for a long period. Examples include base structure material for road embankment or coastal levees, soil cover material for waste landfills, basic soil material for flower farms and energy crops in agriculture etc.

An example of the application of recycling (re-use) of contaminated soil in the construction of a hypothetical embankment is shown in Fig. 29.

The contaminated material is shielded by non-contaminated material ensuring that relevant radiation safety criteria are met. The non-contaminated cover soil has also ensured protection in case of accidents and prevented soil erosion. Radionuclide leakage and dispersion to the surrounding environment has also to be prevented.

The use for soil containing low levels of contamination in civil construction projects in Japan is yet to be analysed.

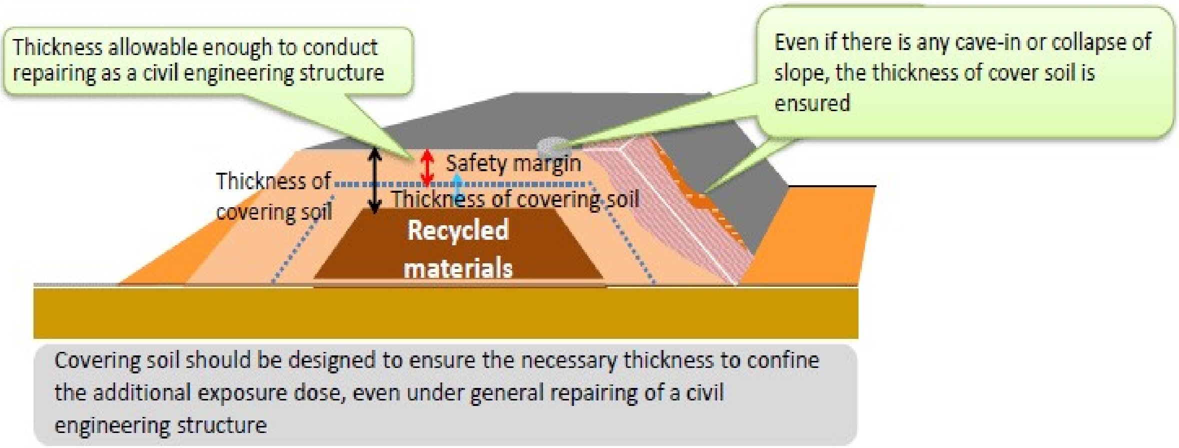


FIG.29. Scheme of recycling of low contaminated soil in the civil construction project (reproduced with permission).

5.7.3. Dose criteria and clearance values for various recycling options

According to the general radioactive waste management regulations, recycled materials cannot exceed a specific activity of 8,000 Bq/kg.

The conditional clearance levels for use of recycled low activity radioactive materials in specific civil construction or other similar applications conform to the following dose criteria:

- The dose to the public resulting from the reuse of recycled material should not exceed 10 µSv/a;
- The dose to workers during construction works should not exceed 1 mSv/a.

Example data on allowable levels for radiocaesium in recycled materials estimated by the MOE using risk-assessment calculations for various applications as a function of shielding by non-contaminated soil are listed in Table 8.

TABLE 8. ESTIMATED ALLOWABLE RADIOCAESIUM CONCENTRATIONS IN RECYCLED MATERIALS FOR DIFFERENT APPLICATIONS [85]

Application of contaminated soil		Shielding condition	Radioactive caesium concentration in recycled materials (Bq/kg) *	The thickness of shielding which is necessary to reduce the additional exposure (cm)
Soil structure (embankment)		Covered with soil or asphalt (e.g. road and railway banks)	≤ 6,000	≥50 cm
		Covered with concrete (e.g. coastal levee)	≤ 6,000	≥50 cm **
		Covered with plants (e.g., seaside protection forest)	≤ 5,000	≥100 cm **
Waste disposal sites	Intermediate covers	Cover soil	≤ 8,000	≥10 cm
	Final covers		≤ 5,000	≥30 cm **
	Embankment		≤ 8,000	≥30 cm
Landfill materials/filler (for subsided ground)		Covered with plants (e.g. seaside protection forest)	≤ 4,000	≥40 cm (grass) ≥100 cm (arbour)**
Farmlands (flowers, energy crop)		Covered with soil (for backfill)	≤ 5,000	≥ 50cm
		Covered with soil (for levelling)	≤5,000	≥ 50cm

* It is assumed that the time for construction is 1 year. The caesium activity concentration value was derived from a dose criterion of 1 mSv/a and rounded to 1,000 Bq/kg. The activity concentration assumes ^{134}Cs to ^{137}Cs activity ratio as of Mar. 2016.

**The cover thickness value includes the combined thickness of soil and concrete structures.

Long-term radiation monitoring of external dose rates, air quality and radionuclide concentrations in run-off and seepage liquid further confirmed that there is no leakage of contamination to the environment and no additional radiation impact on the environment.

The project has provided information and valuable experience on a variety of other technological and radiation safety aspects of recycling contaminated soil, for example on dose conversion factors (from ^{134}Cs and ^{137}Cs specific activity to external dose rate) for construction workers, on record traceability for recycled materials, etc. This experience will be used by the MOE to prepare the ‘Guidelines for Recycling’ document. The project Communication Team was established in September 2017 in order to disseminate the collected experience and foster understanding by the public, local authorities and other interested parties of the soil recycling issues and best practices.

Another demonstration project is implemented by the MOE in the Iitate Village (started in April 2018). The removed soil stored locally in TSS was recycled to infill the agricultural land area (as a base layer). This base layer of recycled soil is covered by clean soil, and the resulting land is subsequently used for the cultivation of flowers and energy crops

The soil treatment process was like the process applied at Minamisoma City. The project area is planned to expand to 34 ha, where the habitation zone and agricultural zone are constructed. The demonstration test is currently promoted, and after constructing an embankment consisting of clean soil on top of contaminated soil, crops in the open air and flowers inside the greenhouse have been cultivated in the demonstration yard of the agricultural zone, The project includes a comprehensive monitoring programme to check operational radiation conditions and possible dispersion and leakage of radioactivity from the recycled soil. The uptake of radioactive caesium by crops has been studied. The results obtained so far show the level of radiation safety that is even higher than was expected from the preliminary safety assessment for this test cultivation. Once the safety is confirmed and the consensus within the community is built, the larger projects will be launched.

5.8. PLANNING FOR FINAL DISPOSAL

As mentioned earlier, according to the Act on Special Measures Concerning Radioactive Materials [35], responsibility for the disposal of waste from decontamination operations is taken by the national Government. The final disposal is intended to be carried out outside the Fukushima Prefecture within 30 years from the start of the interim storage at the ISF.

5.8.1. Final disposal of removed waste from decontamination works

The general roadmap stipulated by the MOE for the final disposal of the decontamination waste outside the Fukushima Prefecture is shown in Fig. 30. The specific options for the location, design, and dimension of the final disposal site will be proposed by the MOE based on technology development and the possibility to reduce the volume of waste for final disposal through waste treatment and soil recycling, and also taking into account radioactive decay. The issue of primary importance would be the development of understanding and acceptance of the option for final disposal by public and local communities.

The site for final disposal is intended to be in an area characterized by low population density and have a favourable geological and hydrogeological setting. In combination with a multi-barrier design, this will minimize, to the maximum possible extent, the likelihood of any adverse impacts of the disposed waste to humans and the environment.

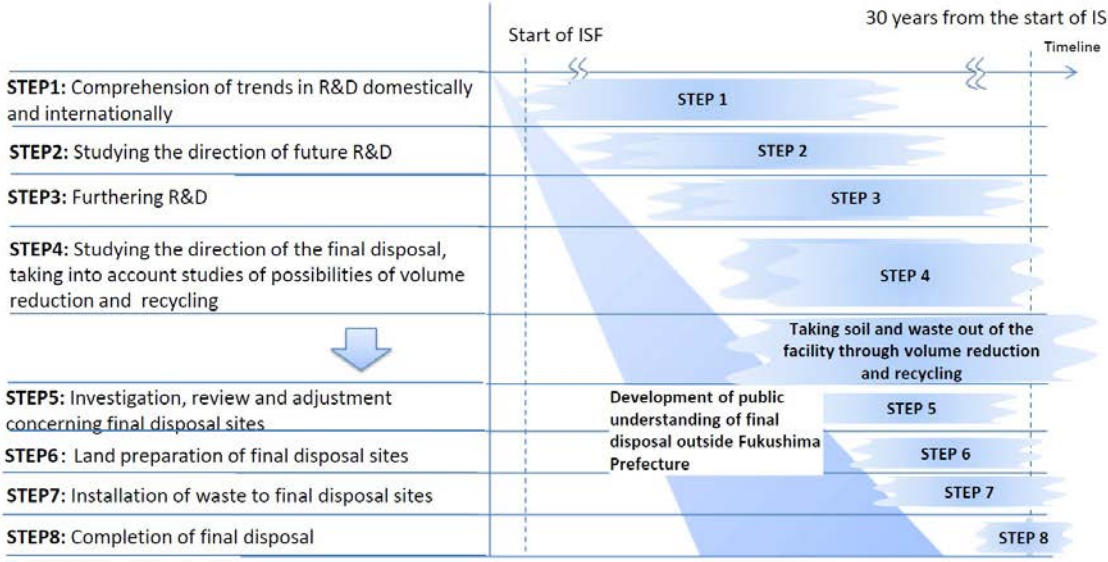


FIG. 30. Roadmap for final disposal of decontamination waste from the Fukushima Prefecture (reproduced with permission from MOE).

5.8.2. Final disposal of the Specified Waste

Waste within Countermeasure areas and the Designated Waste, that fall in the category of 'Specified Waste' are treated by the national government.

The Specified Waste includes radioactive waste other than decontamination waste and removed soil, such as waste generated through house dismantling in the Countermeasure Area, waste generated through clean-up activities by residents, incineration ash etc. The pathway toward the final disposal of the Specified Waste is different depending upon its radiocaesium activity (i.e. if it is above or below 100 000 Bq/kg).

The final disposal for the Specified Waste with an activity concentration of 100 000 Bg/kg or less needs to be carried out in controlled landfill sites equipped with properly engineered barriers and a leachate collection system.

In December 2015, consent was obtained by the MOE from the Fukushima Prefecture, Tomioka Town and Naraha Town for the use of a controlled landfill site in the Fukushima Prefecture (formerly the Fukushima Ecotech Clean Center) for final disposal. The national government nationalized the existing controlled disposal site in April 2016 and has concluded a safety agreement with the Fukushima Prefecture and the two municipalities in June 2016. The transport of the waste material to the facility was commenced in November 2017.

The facility area is approx. 9.4 ha, with the landfill site area approx. 4.2 ha. The landfill capacity is approx. 960 000m^3 of which spare landfill capacity: approx. 740 000 m^3. By 22 February 2021, 166 778 container bags had been transported to the landfill site.

5.9. LESSONS LEARNED FROM WASTE MANAGEMENT ACTIVITIES

The Japanese experience in implementing large-scale remediation works shows that managing the decontamination waste during post-accident remediation is a key challenge and constitutes a potential constraint for planning and implementing the remediation process due to the potentially very large amount of waste to be generated by the different approaches. Waste management (contaminated soil, vegetation, debris, etc.) is then a critical aspect to be thoroughly considered at an early stage of the planning of remedial works whenever decontamination is a major component. Eventually, this aspect may potentially have a significant impact on the selection of the overall approach and the end-state remediation criteria for managing the post-accident contaminated land.

An important consideration is the specific nature of decontamination waste i.e. which mostly has a relatively low activity concentration and consists of contaminated soil, vegetation, etc. This waste is very different from radioactive waste that is usually managed in the nuclear fuel cycle. This aspect needs to be considered when planning remedial operations, as such waste requires specifically tailored techniques to be used in the waste treatment, storage and disposal. It is important to be aware of the fact, that decontamination waste management (including disposal) issues typically will extend into the future far beyond the completion of decontamination works.

In the case of decontamination works, it is crucially important to consider segregation and treatment of decontamination waste for volume reduction, to minimize temporary (i.e. interim) and especially final disposal volumes.

It is equally important to work out practical, safe, and socially acceptable waste (soil) recycling approaches in view of the large amount of material containing relatively low levels of contamination, to minimize interim storage and final disposal volumes.

One of the key lessons learned is that getting the understanding and consent from public and local authorities for various stages of decontamination waste management activities (interim storage, transportation, recycling, final disposal) is a key pre-requisite as well as a potential important constraint on selecting the remedial strategy and its implementation.

Addressing the above-mentioned issues would certainly produce clear benefit regarding better preparedness to deal with remediation activities to be put in place in the aftermath of an unlikely nuclear accident at both the local and national level (e.g. establishing advance role sharing between the interested parties, pre-selection of the sites for TSSs or the final disposal site, etc.).

The activities of managing decontamination waste are in the active phase in Japan and pose numerous technical, logistical, and short–medium term issues that have to be fully and duly considered in any plan intended to address the remediation of large areas affected by a nuclear accident.

6. STAKEHOLDER ENGAGEMENT

6.1. INTRODUCTION

The consequences of widespread and long-lasting contamination are complex and multi-dimensional – with potential impacts on the environment, health, local and national economies, as well as psychological, social, and political impacts. The impacts of evacuation, relocation and recovery activities on people represent wide-ranging disruptions to 'normal' lifestyles. This includes effects on business, employment, public services, education, family networks and community cohesion, which have significant impacts on health and well-being.

6.1.1. Inputs from IAEA–MOE meetings on stakeholder engagement and communication

Stakeholder engagement and communication, as discussed in previous sections, permeate the whole remediation effort put in place by the MOE and constitute an important area of discussion in the scope of the meetings between the MOE and the IAEA.

In the first meeting, the key role of communication of the outcomes of the remediation works to different stakeholders was recognized. In this regard, it was noted that it was very important that relevant information was constantly transmitted to the public using appropriate and clearly defined terminology and that ongoing and planned activities were presented in a life-cycle perspective, and that the views and concerns of the affected community were captured and addressed.

The issue with the so-called 'hotspots' was raised in the second meeting as a source of concern to the communities leaving in the affected areas. The MOE was advised to develop routine hotspot surveying and rapid remediation action plans in the relevant areas. It was also suggested that these plans should be communicated with the stakeholders and this communication could be a key tool to help reduce potential concerns of returnees.

In the third meeting it has been recognized that in practically all actions implemented by the MOE, stakeholder engagement was an essential part of the remediation process. It was also appreciated that many of the decisions have been driven by the stakeholders, especially in the ICSA area where the municipalities oversaw remediation. An interesting point to note is that at the meeting the IAEA experts were informed that some of the adopted decisions were being reconsidered by the stakeholders in terms of their appropriateness. Because of that, the MOE could benefit from considering reorienting future stakeholder engagement practices, especially during the repopulation of the evacuated areas and continuous remediation to reach the long-term clean-up goal. But the point underpinning the discussions was that extensive stakeholder engagement was needed to assist in understanding the rationale behind each remediation option and to clarify, in a transparent manner, all the potential controversial points so that a consensus can be reached on optimized and sustainable management options.

In the fourth meeting, MOE representatives informed the IAEA team of experts that the review of the Act on Special Measures has been conducted by the MOE's Committee for Review of the Act on Special Measures and that review did include aspects related to stakeholder engagement (see Section 6.2.2.). The use of social media was seen as an effective communication method not only with national but also international stakeholders.

6.1.2. The post-accident context for stakeholder engagement

Recovery[8] is the process of rebuilding, restoring and rehabilitating a community following an emergency Remediation can also be seen as part of the recovery process. The process will involve a range of actions to assist communities in returning, where feasible, to a sustainable environment in an acceptable time frame, and to a way of living where the event is no longer dominant in their thinking. The experience of the Japanese in managing recovery from the Fukushima Daiichi nuclear emergency has highlighted three key areas of activity:

- Remediation to reduce radiation exposures arising from environmental contamination. Dose reduction criteria need to account for the wider consequences of protective measures such as economic cost, disruption, time for decontamination and the volume of wastes generated - and balance these;
- Revitalisation to support the restoration of community infrastructure and economic activity;
- Stakeholder engagement and communications to build and maintain the trust and confidence of affected communities in the development of strategies to support recovery.

Embedding stakeholder involvement in national recovery legislation, strategy, planning and implementation has been a hallmark of the Japanese approach to recovery. How remediation and revitalisation activities to support community recovery are undertaken, is critical to their success. Good recovery outcomes are more likely to be achieved where there is effective communication between the civil authorities and those affected and where the community is able to exercise a high degree of self-determination. This means being able to discuss and express views on the strategies and plans that will affect their future. The discussion will cover outcomes and goals for future living that communities wish to achieve, priorities for remediation, the costs (time, disruption, environmental impact, waste generation) and what is feasible. However, communities are not decision-makers [87]. Decision-makers need to listen to, and where possible, take account of the views of affected communities. For example, surveys of evacuated populations indicate that public confidence in the safety of Fukushima Daiichi NPP and associated radioactive waste management have influenced decisions on whether to return [88]. The overall cycle of decision-making for late-phase recovery from the major nuclear or radiological event from Ref. [88] is represented in Fig. 31.

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[8] The IAEA Safety Glossary [3] does not provide a specific definition for recovery.

FIG. 31. Decision making for late-phase recovery from the major nuclear or radiological event (reproduced from [87] with permission).

6.1.2.1.The impact of crises on affected communities

For many, the experience of the Fukushima Daiichi NPP accident (and tsunami) will have been a traumatic and life-changing event. Emotional responses will vary. Acute responses may affect objectivity in assessing future options for returning to a new normal. This will shape peoples' views of what should happen next. Stakeholder engagement in the context of remediation after an accident will need to take account of recent community experience.

Activities to remediate areas affected by radioactive contamination are framed by multiple technical considerations. These include remediation technologies, tolerability of risk, waste management strategy and environmental monitoring to verify intended outcomes. Stakeholders, whether national or local governments, nuclear operators, citizens or landowners, will play a key role in shaping how remediation is implemented – including what is feasible and acceptable.

6.1.2.2.Stakeholder experience in the context of a crisis – what it means for engagement

Stakeholders have an important role play in the remediation of legacy sites contaminated by past practices involving radioactivity. However, the situation in the aftermath of a nuclear accident presents a different context and a significant challenge for communities affected. People living in areas contaminated by the release of radioactivity will present psychological and emotional responses which distinguish their attitude and state of mind from those living in the vicinity of a legacy site.

People experienced fear of the accident itself and may have been evacuated causing immediate and catastrophic changes to their way of living. They may have lost their homes and belongings, been separated from their neighbours and communities and experienced significant disruption to daily routines. A period of acute uncertainty will have followed. People will have listened to a range of experts with different and sometimes conflicting views. They may believe they are being deprived of information. They will be anxious about the levels of contamination where they lived and whether it will be safe to return and will want to know when and if they will be allowed to. Emotions including anger, frustration and loss of trust are inevitable in the psychological environment following a nuclear accident, meaning that sound rational discussion may be difficult.

6.1.2.3.Communicating the post-accident reality

The national government and local authorities will have an important role in communicating and explaining the post-accident reality to affected communities, what it means for day to day living and how this is likely to change over time. This will involve explaining unfamiliar concepts. For example:

- What decontamination can and cannot deliver. The environment contains naturally occurring radioactivity. The accident will have released radioactive material resulting in environmental contamination. Whilst decontamination offers a mechanism for reducing levels of radioactivity in the environment, return to pre-accident conditions is highly unlikely (and eventually not even necessary) without significant disruption, delay and impacts on community cohesion, local economy and lifestyle;
- Exposures to contaminated environments post-accident will vary geographically and over time. The factors affecting variation include atmospheric and environmental dispersion, land use, occupancy and diet. Most exposures will not present a significant health risk. The factors affecting dose need to be explained carefully: otherwise, people will imagine the worst;
- How ionizing radiation affects the human body and health - including a distinction between deterministic effects and stochastic effects and the concept of latency.

Effective and targeted dialogue will be needed to help people understand and engage with these concepts. Factors affecting how the message is received include:

- How the message is presented;
- The messenger, including whether or not they are familiar and trusted;
- Consistency of messaging;
- What others, such as scientists, pressure groups and agencies, are saying;
- Peoples' perception of the messenger as being supportive or not supportive of stakeholder views.

6.1.2.4.Understanding the impact of perception on health

As noted elsewhere in this report, the health impacts from exposure to contaminated environments in the aftermath of an accident, will be low and not at all comparable with, for example, the extremely high doses received by the Chernobyl liquidators. Despite, this knowledge, people living in contaminated environments will be anxious about radiation-related diseases and in particular, cancer. It is well known that the relationship between dose and risk of cancer in the domain of low doses is probabilistic.

At low doses, a large sample population will be needed to attribute any increase in the incidence of cancer. The calculated excess cancer incidence from low doses of radiation from environmental contamination will in general, not be distinguished from the natural cancer incidence in the population. Also, the latency period between radiation exposure and cancer detection means that it will take a long time for cancer to be noticed. However, experience shows that all this information per se may not be enough to facilitate the discussions and reduce the anxiety of affected populations. In the meantime, any cancer case observed in the affected population will automatically be attributed to the accident, including those cancers which are not typically radiation induced. Other perceived increases in the incidence of disease will also be attributed to radiation exposure. Perceptions will be reinforced by support for these beliefs published in the scientific literature, even though the association with radiation exposure would be refuted by other experts.

Other health detriments may well be attributable to the release of radioactive substances from a nuclear accident. Mental health is an equally important aspect of our lives. The immediate impacts of the accident such as evacuation, and the longer-term anxiety of living in an environment contaminated with radioactive substances may lead to depression, a sense of emptiness, lack of purpose and social disengagement which impairs normal living.

6.1.3. Purpose

This section is particularly relevant for professionals with a role in future planning and implementation of recovery from nuclear and other radiological emergencies, such as officials from the local and national government, public agencies and organizations, subject matter experts and academics. However, it is also aimed at community representatives and stakeholders who may be targeted for stakeholder engagement, so they understand the drivers for stakeholder engagement and the barriers to delivering effectively.

The intention is to provide an insight for planners and responders on the learning for stakeholder engagement from the Japanese experience of Fukushima environmental remediation and revitalisation. This section:

- Sets the scene by describing the post-accident context for stakeholder engagement;
- Explains how the mechanisms to ensure the views of people and communities affected by environmental remediation were captured in legislation, policy and strategy to frame the Japanese remediation efforts;
- Provides examples of how stakeholder engagement was coordinated nationally and locally to achieve common goals;
- Explains the Japanese approach to post-Fukushima stakeholder engagement notably to provide scientific information and promote dialogue;
- Highlights current international good practices and suggestions for stakeholder engagement in post-accident environmental remediation;
- Takes a thematic exploration of the drivers and challenges to stakeholder engagement based on the observations of the IAEA expert group covering the following topics:
  (a) Coordination of communications and stakeholder engagement;
  (b) Inclusivity – age, gender, ethnicity, vulnerable groups;
  (c) Building and maintaining trust;
  (d) Managing community anxiety and providing reassurance;
  (e) Effective leadership;
  (f) The role of science and scientist in stakeholder engagement;
  (g) The international community as a stakeholder;
  (h) Cultural influences;
  (i) Consequences of stakeholder interactions - impact on decisions and actions;
  (j) Supporting community involvement in decisions;
  (k) Measuring success.

- Considers the perspectives of science and research on stakeholder engagement, in particular the wider social, political and economic factors that play into decision making for post-accident remediation;
- Concludes by highlighting lessons identified.

6.2. FRAMEWORKS FOR STAKEHOLDER ENGAGEMENT

This section highlights key recommendations of international guidance on the development of frameworks, legislation, strategies and plans to manage post-accident remediation and stakeholder engagement. It explains how stakeholder engagement came to be embedded in Japanese efforts to manage post-Fukushima recovery and remediation, the role and responsibility of administrations, utilities, subject matter experts and members of the public. It also describes how stakeholder engagement was planned, managed and coordinated and provides examples of how key expectations for stakeholder engagement have been met.

6.2.1. Legislation, strategies, and plans

IAEA Safety Standards Series No. GSR Part 1 (Rev. 1), Governmental, Legal and Regulatory Framework for Safety [89] identifies well-developed governmental, legal, and regulatory frameworks as the prerequisites for effective remediation. The basis for the national framework for remediation is a national policy and corresponding strategy, as well as the legal and regulatory instruments necessary to implement policy and strategy. These requirements provide the context for the Act on Special Measures Concerning Radioactive Materials approved by the Japanese parliament on 26 August 2011.

6.2.1.1.International guidance

It is proposed in Ref. [90] that national remediation policy is essential for establishing the core values on which remediation is to be based. In addition, the “environmental remediation policy will set the nationally agreed position and plan and will give visible evidence of the concerns and intent of the country”. Ideally, the policy and strategy are in place prior to an accident. This allows stakeholder dialogue to take place away from the emotionally charged post-accident environment. This facilitates rational debate, provides time to explore and achieve consensus on important topics and produce a policy document owned by those who have shaped its development. Reference [90] also recognises that stakeholders will have diverse and potentially conflicting interests in terms of remediation goals, implementation time frames, future use and/or reuse of affected sites, techniques, and technologies to be applied and cost allocation. From a stakeholder engagement perspective, important policy areas to be covered include:

- The role and responsibility of government departments, agencies and organizations involved;
- The process for site remediation includes who will do what, site-specific milestones, and very importantly, public expectations;
- How the waste produced by remediation will be managed;
- Funding considerations, potentially in line with the ‘polluter pays’ principle;
- Prioritisation of remediation activities, which take into account the social and political context, public perceptions, risk assessment and resources available.

Critically, policy needs to include public participation in the decision-making process, and how the decisions will be made because of such participation. The decision-making process and the resulting remediation solutions will be of interest to a wide range of stakeholders, not only people living in the affected areas (local communities) but also the general public.

Stakeholders will be from diverse backgrounds, with different levels of knowledge, education and experience. Ideally, all stakeholders are involved in the decision-making process, with equal consideration being given to professional and lay knowledge. The aim is to achieve a shared understanding across all parties of the situation and its implications. Information made available to support discussion would include the relevant medical and scientific literature, details of the affected area and views derived from the experience of local people. The economic, social and health impacts of leaving sites in their present condition, and of different methods of remediation, need to be discussed openly.

The second IAEA Mission to Japan on remediation [5] noted that "It is crucial that opportunities are sought to ensure citizens understand that the remediation process often involves a balance between reducing exposure risks and increasing waste volumes". As well as understanding the concept of risk, stakeholders need a holistic understanding of the remediation life cycle. This allows them to better understand the implications of each decision being made so that such decisions are not assessed in isolation. Achieving this requires a proactive rather than reactive approach to engagement. For example, understanding the amount of wastes generated from different decontamination techniques points to the need for TSSs that may be located within the affected area or elsewhere. From this, the cost and environmental impact of transporting the wastes from the generating locations to the storage and/or disposal sites needs to be considered.

There is also an important distinction between a decision-making process that takes account of the input of different stakeholders and one which is driven by stakeholders where their position is based on perception rather than hard evidence. The presence of misinformation will be critical here. The existence of policies that establish how this decision-making process will take place is therefore crucial for what can be termed a successful remediation endeavour.

Reference [90] draws some important conclusions about frameworks for remediation:

National policies and strategies for the remediation of contaminated land vary from country to country but share some common elements:

- There is no single policy model for dealing with the subject, and no single model would be workable for the entire world;
- Policy and strategy elements need to be addressed adequately with regard to the extent of the remediation problem;
- Much of the policy and legislation on environmental remediation is in its infancy; so, there is little evidence as to which approach is the most likely to produce the best results;

Comparing current experience, a system of good practices could be suggested to aid those countries that do not yet have an environmental remediation policy.

6.2.1.2.Recent developments

IAEA Safety Standards Series No. GSG-15, Remediation Strategy and Process for Areas Affected by Past Activities or Events [91] provides an outline framework for stakeholder engagement. As GSG-15 [92] was published in 2022, there can be no expectation that its recommendations could be fulfilled in the context of remediation from the Fukushima nuclear accident. However, these recommendations stress the importance of involving interested parties in the development of the national strategy for remediation and continuing their involvement in the subsequent development of a site or area remediation strategy. GSG-15 [92] sets out:

- The responsibility of the government for making provision for the involvement of interested parties and how this will be coordinated. Who should be involved? What information needs to be shared? Who is the audience? All this information will be needed;
- The need for a stakeholder engagement strategy and plan to ensure harmonised public relations are established and conflicting messages avoided, and which takes into account the following:
  - (a) Involving public and interested parties as early as practicable;
  - (b) Adopting a range of engagement formats – selecting those best suited to the aims of engagement, topics under discussion and the needs of the stakeholder community;
  - (c) The role of the regulatory body – in informing interested parties, public, news and media about risks and how to manage;
  - (d) Using plain, clear and unambiguous language;
  - (e) Planning communications to avoid causing anxiety.
- Issues for consultation with stakeholders:
  - (a) Health effects of radiation, including the retrospective attribution of radiation health effects to past radiation exposures and the prospective inference of health risks from exposures that have occurred or are expected to occur, assumptions and uncertainties;
  - (b) Actual risks and perceived risks.
  - (c) Radiation risks and safety before remediation, during remediation work, during the management of wastes, and after remediation;
  - (d) Graded approach to protection and safety.

6.2.2. The Japanese framework for stakeholder engagement

The Act on Special Measures Concerning Radioactive Materials established a sound platform on which the necessary stakeholder engagement activities were developed and designed. It provided the legal framework for stakeholder involvement and communication in remediation and waste management activities by clarifying the responsibilities of relevant stakeholders, including national and local government, nuclear power producers and citizens. This included a responsibility to implement and cooperate with measures taken to deal with environmental pollution from radioactive materials released by the accident. In so doing, it clarified the responsibilities of the following stakeholder groups.

6.2.2.1.The Act on Special Measures and the role of stakeholders

From the information available, there was previously an absence of clarity on which government department or agency was responsible for overall leadership and coordination of stakeholder engagement, including the development of national strategy and plans. However, the Act on Special

Measures Concerning Radioactive Materials placed new stakeholder engagement obligations on national and local government and covers many of the key elements recommended in international guidelines, as mentioned in Section 6.2.1.1, as follows:

- To prepare basic principles for the management of environmental contamination and to consult with stakeholders;
- To inform the public promptly and accurately about remediation plans and activities and risks to the public;
- To establish a unified system for monitoring and measurements of doses and to disseminate the results to the public;
- To consult on remediation plans. For example, in the SDA, the MOE consulted with relevant administrative bodies. In the ICSA, prefectural governors consulted with representatives of national government, prefectures, municipalities and implementers.

Further information on stakeholders and their responsibilities is presented in Table 9.

TABLE 9. STAKEHOLDERS AND THEIR RESPONSIBILITIES AS SET OUT IN THE ACT ON SPECIAL MEASURES

Stakeholder	Responsibility
National government: the MOE	Policy and standards; Remediation and waste management in the SDA; Transportation of contaminated materials to the ISF; Operation of the ISF (Classification, Storage, Volume reduction); Final disposal of contaminated waste outside the Fukushima Prefecture; Technical and financial support to local government.
National government: The Cabinet Office / the Reconstruction Agency [92]	Support for evacuees; Housing, reconstruction and community development; Reviving industry and livelihoods; Revitalising and reconstructing Fukushima including a task force on measures to counter the impacts of nuclear hazards including reputational damage; Systems to support reconstruction including finance, legal systems and support to local government.
Prefectural and Municipal government	In the ICSA develop and implement remediation and waste management plans; In the ICSA siting of TSSs; In the ICSA restoring the original condition of TSSs after completion of waste and soil transportation.
Nuclear power companies (the TEPCO)	Assist national and local government remediation and waste management efforts; Cover the cost of remediation under the Act on Special Measures Concerning Radioactive Materials.
Citizens and landowners	Cooperate with national and local governments in managing wastes contaminated with radioactivity.

6.2.2.2.Other stakeholders not mentioned in the Act on Special Measures Concerning Radioactive Materials

Although not mentioned specifically in the Act on Special Measures Concerning Radioactive Materials, other stakeholders, including academics, subject matter experts and contractors, had an important role to play in supporting post-accident remediation and revitalisation.

Technical Advisory Council on Remediation and Waste

In November 2011 the Technical Advisory Council on Remediation and Waste Management was established. The 67-member organizations with interests as diverse as construction, civil engineering, environment, radiation protection, waste management and transportation, came together to share information on technologies and optimization for decontamination scenarios. In line with its agenda on social and corporate responsibility, the Council aimed to contribute to the smooth implementation of decontamination activities in support of national and local municipalities.

Atomic Energy Society of Japan (AESJ)

The AESJ seeks to progress the peaceful use of atomic energy through academic research and advances in technology. Members volunteered their expertise to support the progress of remediation by providing an independent interface between the government and other authorized bodies involved in the work and the people affected. The AESJ had developed an important ‘independent’ role in providing information and explaining radiological risks and the technical aspects of remediation. Their activities included:

- Public information: Hosting public seminars and discussion forums and providing specialists to the Remediation Information Plaza, Fukushima City. For example, between March 2012 and December 2017, at weekends and holidays, a total of 800 AESJ volunteers provided expertise in support of visitors to exhibitions and events at the Plaza;
- Operational activities:
    (a) Implementation of remediation in support of municipalities;
    (b) Introduction of EURANOS [93] capabilities by translating the approach into Japanese and developing a remediation handbook for residents;
- Research on uptake of radioactive caesium into rice in a practical paddy field at Minami-soma.

The Society for Remediation of Radioactive Contamination in the Environment (SRRCE) was established in the aftermath of the Fukushima Daiichi NPP accident to provide a common platform for the exchange of new radioactive decontamination technologies and expertise. Most interactions take place online, and participants are encouraged to interact and network with each other. SRRCE also provides seminars, panel discussions and journal publications for members across the globe. Society activities picked up pace with the commencement of decontamination activities in Fukushima. The society issued publications on the characterization of radioactively contaminated soil, and technologies of decontamination, removal of radioactive caesium from the soil, soil washing, soil recycling and reuse, waste incineration and reachability from the residue, and transferring radioactive materials into animals In Fukushima.

Fukushima Medical University

Committed to patient care, education and research following the nuclear emergency, the Fukushima Medical University broadened its mission to promote the long-term health and well-being of Fukushima residents. University research activities have provided important insights on the impact of the events on the environment and health:

- Monitoring of environmental contamination:
  - (a) Specific villages, towns and agricultural land;
  - (b) Sampling and analysis to understand levels of radioactivity in soils and uptake into plants.

  Dose measurement and assessment,
- Health surveys:
  - (a) Developing protocols for long term health monitoring;
  - (b) Mental health–anxiety, bipolar disorders, post-traumatic stress disorder, problem drinking;
  - (c) Physical health – incidence of thyroid cancer, leukaemia;
  - (d) Impacts on the elderly.
- Stakeholder engagement:
  - (a) Long term impacts of the accident for emergency medical teams and health care workers;
  - (b) Relationship between intention to return and perception of health risk due to radiation exposure in Tomiaka town [94];
  - (c) Assessment of stakeholder engagement interventions e.g. effectiveness of group work exercises [95].

Contractors and suppliers

As already mentioned elsewhere in this report, a considerable number of workers were involved in the remediation efforts covering the SDA and ICSA. In collaboration with local government, contractors and suppliers contributing to remediation projects also took the initiative to reach out to affected communities with information, advice, and support. This was aimed at building an understanding of decontamination works and trusted relationships with landowners and residents. Typical formats for engagement included websites, setting up local information 'hubs' and involving residents in monitoring dose rates in the air before and after the setting up of TSSs. Contractors also held meetings to explain proposed decontamination activities and what could and could not be achieved. Several contractors invited community representatives to attend site inspections. A broad description of what contractors are supposed to do in remediation works is offered in [96].

6.2.2.3.Legislation, national strategy, and planning

There appears to have been limited opportunity for stakeholder engagement in the shaping of the Act on Special Measures Concerning Radioactive Materials. This was a matter of routine parliamentary process, albeit undertaken at pace in the context of a national emergency. Had the shaping of legislation for recovery, rehabilitation and remediation been developed as part of emergency preparedness, there may have been an opportunity for a formal consultation with representatives from relevant government, prefectural and municipal agencies. From this follows the possibility for stakeholder engagement in:

- National policy (vision, principles, governance);
- Strategy (outcomes and objectives, measures of success);
- Coordination;
- Operational plans (delivery of remediation activities on the ground.

Due to the post-accident urgency to establish the Act and basic policy concerning remediation areas and reference levels, roles and responsibilities, there was limited scope for wider stakeholder engagement. It is reasonable to speculate that key policy decisions which shaped the future direction of the remediation effort were not afforded the deeper exploration, scrutiny, and debate that the involvement and expertise of relevant stakeholders would have provided.

6.2.2.4.The Act on Special Measures Concerning Radioactive Materials– 3-year review

Article 5 of the Supplementary Provisions of the Act on Special Measures Concerning Radioactive Materials included a requirement to review the enforcement status of the Act, three years after it became law. To implement this provision, the MOE set up the Investigative Committee. Membership was drawn from across the industry, academia, and research institutes, encompassing a wide range of disciplines. For example, nuclear technology, health sciences, environment, and waste management technology. A journalist was also included in the membership of the Investigative Committee. The group met five times between March and September 2015 with the purpose of reviewing the implementation status of various measures based on the Act and to advise on the shaping of future policy. Topics covered by the review included:

- Policy-based on the Act on Special Measures Concerning Radioactive Materials;
- Goals and ‘roadmap’ for decontamination;
- Approaches to and guidelines for decontamination in different environments;
- Conditions in temporary storage sites;
- Progress on decontamination;
- Stakeholder engagement.

To provide an evidence base for the work of the committee, in March 2015 the MOE distributed a questionnaire to the municipalities involved in decontamination activities. The committee’s report [97] was published on 30 September 2015. Whilst no amendments to the Act on Special Measures Concerning Radioactive Materials were recommended, issues for consideration were highlighted across all areas of evaluation. On stakeholder engagement, the following observations were made:

- Education about radiation and health is a matter for the national government, not just the MOE and should be tackled comprehensively.
- National and local governments need to clarify roles and cooperate when explaining the risks associated with environmental contamination and the proposed remediation efforts. This aims to ensure consistency of messaging and build confidence and trust.
- Be realistic about how long remediation activities will take to implement. Manage stakeholder expectations in this respect.

- Provide understandable explanations of what radiation dose rates mean for health impact and in reference to international standards.
- Give greater focus to dialogue and explanation on the treatment of designated wastes outside the Fukushima Prefecture.
- Be clear and transparent on the progress of decontamination and reconstruction.

6.2.2.5.Coordination of stakeholder engagement and communications

For the first few years of post-accident remediation efforts, there has been limited evidence of an overarching communication strategy. There was no structured organization in charge to coordinate the totality of communication and stakeholder engagement efforts. It is not obvious whether this would have been effective in ensuring a clear and consistent message delivery. Since shortly after the accident, the stakeholder engagement and risk communication activities relevant to decontamination works have aligned with the designation of roles established in the Act on Special Measures Concerning Radioactive Materials. In general, the MOE took the lead on public communications and stakeholder engagement in the SDA, with prefectural and municipal administrations coordinating in the ICSA. However, in December 2017, the Japanese government published the Strategy to Strengthen Reputation Management and Risk Communication [98].

In this strategy, the MOE coordinated communications and engagement on environmental remediation and revitalisation and the MAFF conducted surveys to understand consumer confidence in Fukushima produce and campaigned to promote Fukushima food products in wider markets. Moreover, the Ministry of Foreign Affairs (MOFA) promoted Fukushima products taking diplomatic events (e.g. receptions, conferences) as opportunities.

The strategy had three key strands:

- The first strand was “Let the People Know”. The aim was to provide for the understanding of the views of affected communities as well as promoting the understanding of radiation risk through focused and visible messaging. It was necessary to be inclusive and that meant using a range of media channels and formats to reach diverse communities. The target audience included students, teachers, parents and guardians, expectant and nursing mothers. The message can be focused on radiation and its impact on health as well as on food and water safety and demonstration of revitalization progress. Examples of engagement activities include the dissemination of public information, health checks and support for businesses in affected areas.
- The second strand was “Let the People Eat”. The aim was to promote confidence in Fukushima agriculture, fisheries and food at home and abroad. The target audience was composed of retailers, distributors, Permanent Missions to Japan abroad, media platforms and tourists. The message consisted of the quality and safety of Fukushima produce and cuisine as well as food safety standards and monitoring. Engagement activities included the promotion of Fukushima food products at home and abroad; monitoring and survey of Fukushima products in the Japanese market and efforts to lift or loosen the restrictions for the importation of Fukushima products.
- The third strand was “Let People Come” The aim of this initiative was to restore confidence in Fukushima as a tourist and business destination. The target audience was composed of teachers, tour companies, tourists and international media, foreign nationals living in Japan, international travellers to other prefectures. The key message was focused

on Fukushima visitor attraction, environment and food safety and support for educational tourism.

The engagement activities included the promotion of tourism and understanding the views of participants in trial tours, promoting the J-Village athletics centre and development and implementation of the "Commutant Fukushima" strategy to entice people to visit the Prefecture.

In coordination with the stakeholder engagement implemented by government ministries under the 'Know, Eat and Come' strategy outlined above, there have been many other examples of effective cooperation on stakeholder engagement. These involved national and local government working together with academics, radiation experts and community professionals to support peoples' understanding of the post-accident efforts to manage risk to health and the environment. Examples of these initiatives are provided below.

The 'Counselling Services for Returning Evacuees' was established aiming at delivering information and support to affected communities through effective coordination and collaboration. The main components of this initiative are described below:

- Aims and objectives of stakeholder engagement: Following the lifting of evacuation orders, the Japanese government committed to supporting the return of evacuees to their homes. Providing reliable, accurate and trusted information to address peoples' concerns was key to building confidence in decisions to return;
- Proposed stakeholder engagement approach: To provide this assurance, the MOE worked with municipal authorities to embed radiation counsellors in cities, towns and villages - supported by up-to-date information and technical and scientific resources to deliver their role. In 2014, the MOE set up the Radiation Risk Communication Counsellor Support Centre in Iwaki City. This provided support to counsellors and local government staff in addressing a wide range of community needs;
- Stakeholder engagement activities: The Counsellor Support Centre included space and facilities for individual consultation, seminars and discussion groups covering the basics of ionizing radiation, health impacts and how to manage radiation exposure. Counselling services were delivered through practising counsellors, as well as medical practitioners and volunteers;
- Observations and lessons identified: The counselling services improved access to reliable, accurate and up to date information for returnees. Provision of continuous, consistent, community-wide support on technical and scientific aspects of the remediation cannot be delivered by municipal authorities or counselling services alone. It requires national and municipal coordination in collaboration with community professionals and radiation experts.

In 2016, a cabinet decision strengthened resources for the Radiation Risk Communication Counsellor Support Centre to expand and develop services delivered by local government. This included training for teachers, social workers and health professionals on radiation safety and access to backup support from radiation experts.

Another initiative was the 'Environmental Remediation Information Plaza' set up in Jan. 2012, by the MOE in collaboration with the Fukushima Prefecture near the Fukushima Station. This is an example of effective coordination and collaboration on stakeholder engagement involving the MOE (national government) and the Fukushima Prefecture.

As remediation efforts progressed in the Fukushima Prefecture, there was growing public concern about environmental contamination and health, the decontamination process, how long it would take and its effectiveness. Typical questions raised by members of the public included:

- When will my house be decontaminated? How long will it take?
- The school playground has been decontaminated, what about the trees?
- Why have some municipalities made more progress on decontamination than others?
- What steps can I take to reduce contamination of my home and garden?
- I'm worried that contaminated water from cleaning gutters is contaminating rivers and the sea.

The aims and objectives of stakeholder engagement in this initiative can be summarized as:

- Respond to public concerns by providing accurate and up to date information on decontamination and radiation, promptly and clearly;
- Promote communication and engagement with the affected communities;
- Provide a hub for managing requests for support and advice;
- Promote cooperation between the national government, Fukushima Prefecture and other supporting agencies and organizations.

The Decontamination Information Plaza provided a hub for:

- Addressing queries and information requests from the public;
- Briefing and training of professionals working in the community on radiation protection and remediation;
- Despatch of radiation protection experts to support community workers, local government personnel and school students and teachers;
- Exhibitions, seminars, workshops and meetings;
- Stakeholder dialogue and to understand peoples' perceptions, views and opinions of the progress on remediation.

Local authorities and government need to value and be ready to coordinate the deployment of radiation protection professionals who volunteer their time to support community engagement. Public information needs to change as the post-accident recovery and remediation efforts progress. Authorities needed to adapt stakeholder engagement activities from the explanation of radiation concepts to developing a radiation protection culture.

'Supporting Return from Evacuation' is another example of a relevant stakeholder engagement initiative. This one constituted a collaboration between Nagasaki University and Kawauchi Village Office [99]. The Kawauchi Village is located 30km from the Fukushima Daichi NPP, and residents were instructed to evacuate on 15 March 2011. It was the first village to receive returnees after lifting the evacuation orders applying to selected areas in October 2014. Disruption to infrastructure, economy, and business, as well as long term impacts of evacuation and relocation, had delayed Fukushima revitalisation and reconstruction. Operations were transferred back to the village in March 2012. In April 2013, Nagasaki University formalised its commitment to provide ongoing assistance on reconstruction with the Kawauchi municipal office.

In this case, the aims and objectives of stakeholder engagement were:

- Sustain recovery efforts in the village by providing technical and scientific services;
- Evaluate the effectiveness of decontamination;
- Monitor radioactivity in food and water and assess exposures from ingestion pathways;
- Provide information and advice on environmental and health impacts.

The main stakeholder engagement activities consisted of:

- A public health nursery and a satellite office of the Nagasaki University located in the village to provide access to support and advice;
- Communication of the radiation risk situation and advice on progress towards recovery of day to day living. This included village lectures; briefings for village leaders and community professionals, such as teachers, carers and health workers; and education and training for children in collaboration with local schools.
- Activities targeted at community concerns such as:
    - (a) Health implications of consuming wild mushrooms. The advice was provided based on sampling and analysis;
    - (b) Understanding external doses. Personal dosimeters were provided to returnees and results were explained. This led to the lifting of the evacuation order by the MOE and the Kawauchi village office in April 2013;
    - (c) A survey of residents to understand the barriers to returning to their home town.

Cooperation between residents, specialists and community professionals with the support of the local and national government, enhanced the pace and effectiveness of disaster crisis recovery. With appropriate support, people affected by the crisis can play their part in reconstruction and restoration, creating a sense of ownership and purpose in the steps towards recovery. Dose reduction is one factor amongst many — including health, societal, psychological, cultural and ethical factors — that need to be accounted for in strategies to support community recovery.

It is important also to mention that local government and communities need to understand how radiation risk disrupts critical infrastructure such as health services and education, businesses and ‘normal’ ways of living.

The example of Date City is also worth mentioning in terms of how decisive action and effective leadership can help in maintaining confidence in local government. In this case, the initial evacuation orders for the Fukushima Prefecture embraced an area within a 3 km radius from the Fukushima Daiichi NPP. That happened on 11 March 2011. This was then extended to 20km on 12 March. The Date City Disaster Newsletter at the time stated that there was no need for concern because the city was outside the evacuation zone. By end of March, monitoring revealed radiation dose rates in the school playgrounds above 3.8 μSv/h. This was a level at which children should not engage in outdoor activities. The national government designated the nearby Iitate Village a ‘deliberate evacuation area’ but offered no specific advice for Date City. This led to a loss of trust in the national government prompting decisive action from the city council.

In this case, the aims and objectives of stakeholder engagement included:

- Address peoples' anxieties caused by lack of knowledge and trust, confusing and changing positions of the national government and the diverse opinions of experts;
- Maintain public confidence and trust in the Date City administration;
- Address people's ambition to return to normal life as soon as possible.

The Municipal Council felt national government solutions would take too long and decided to drive decontamination by themselves and verify effectiveness through monitoring. The Date City Mayor used his network to engage support and expertise; for example, engaging with retired nuclear experts. He involved TEPCO in environmental monitoring to understand the impact of environmental contamination in terms of radiation exposure. The approach for decontamination was established as below:

- > 20 mSv/a: recommended for evacuation;
- > 5–20 mSv/a: decontaminate at pace;
- < 5 mSv/a: short term target for dose reduction in Date City.

Stakeholder engagement activities involved capturing the views of residents on topics like decontamination (positive reaction) and establishment of TSSs (negative reaction). In addition, dosimeters were provided to 52 783 citizens to monitor individual exposures between June 2012 and July 2013. Some of the residents received follow up whole-body measurements. Residents were provided information and advice that addressed technical aspects, as well as social impacts on families and communities. Finally, residents were also assisted with the clean-up effort under the guidance of experts. It has been seen that a graded approach to decontamination saved money and time, without compromising dose reduction. Decontamination was completed by March 2014. Additionally, confidence in municipal authorities was maintained while residents were empowered to track their radiation exposures, something that led to the strengthening of confidence in the adopted measures. Room does exist to compare the decontamination approaches used in situations of radioactive contamination with those used in incidents with chemical substances [100]. The example of Date City is important as the lack of trust in the national government prompted decisive action from the city administration. In the city's pursuit of dealing with the situation, strategic objectives were defined early and were followed through with decisive action. In this context, leadership needs to be visible and remain connected to communities to build and maintain trust. Leadership is translated by an effective administrative team that gained support from members of the public with the consequent implementation of remedial actions at a reasonable pace. It is also important to clarify that the financial resources within the local budget were made available taking into account that the expenses would be charged to the TEPCO at a later stage. That was indeed a great contribution to the success of remediation efforts.

6.3. STAKEHOLDER ENGAGEMENT APPROACHES IN JAPAN

How activities to support community recovery are undertaken is critical to their success. Good recovery outcomes are more likely to be achieved where there is effective communication and engagement between the civil authorities and those affected [101].

6.3.1. Need for the engagement with stakeholders

Stakeholder engagement played a key part in shaping strategy, plans and initiatives to support post-Fukushima recovery, remediation and revitalization. Actions included:

- Communication of risk;
- Building trust and promoting dialogue;
- Understanding perceptions, concerns and future aspirations of affected communities;
- Testing the acceptability or reaction to proposals;
- Assessing the response and reaction to initiatives implemented;
- Influencing and changing behaviours;
- Encouraging cooperation or participation;
- Learning from good practices.

6.3.2. Approach to post-Fukushima stakeholder engagement

The role of the Japanese authorities, through the MOE, has been two-fold: to support long-term health management through environmental remediation and restoration; and to explain and communicate the risks with stakeholders. This has involved providing scientific information and promoting dialogue with a range of audiences including residents and affected communities.

The main purpose of stakeholder engagement was not to convince parties involved to accept pre-established concepts or even to achieve consensus. Rather, it followed a recognition that remediation objectives were more likely to be achieved by facilitating cooperation and understanding of stakeholders including local residents, landowners, councils, administrative districts, mayors and others. This means the focus of post-Fukushima stakeholder engagement has been to promote trust and understanding.

The MOE supported the long-term health management of Fukushima residents that included measures in relation to risk communication and health consultation. It also included being provided for mental health by means of different initiatives. This involved holding explanatory meetings for residents at each stage of the remediation process. Depending on the scale and contamination situation in the areas affected, explanatory meetings, updates and workshops were carried out regularly, on weekday evenings and during the weekends. More than 100 events took place in a year.

“Stakeholder engagement also played an important part in dispelling widespread rumour and misinformation in the aftermath of the Fukushima accident. For example, there was an ill-informed belief among receiving communities that evacuees were infected with radiation which could be transferred on contact. Dispelling rumour and its stigmatizing impact on evacuees was crucial to psychological recovery following the trauma caused by the accident, as well as supporting social integration and community recovery. Dialogue to explain the science in schools and communities was a key element of post-Fukushima stakeholder engagement” [102].

6.3.3. Providing scientific information

The MOE website ‘Information Site on Environmental Contamination by Radioactive Materials’ [41] was launched in January 2012. This is now called the Decontamination Information website. This provided a ‘one-stop shop’ for information on the health effects of radiation, updates of environmental radiation monitoring results and updates on the progress of decontamination [102]. The website design and content were updated regularly to respond to information needs.

Content is organized around themes such as i) Decontamination; ii) the ISF; iii) Movies and Publications; iv) Policy and documents.

The Fukushima Prefecture Website also released information for affected communities, with a focus on the safety of food and water, progress towards environmental restoration and revitalization [101].

Another initiative of the MOE was related to providing consistent, reliable, and accurate information on radiation risk. That initiative was motivated once the response to the Fukushima Daiichi NPP accident moved from the emergency phase to recovery, differing concepts of radiation risk emerged among local governments. This caused confusion and concern for people living in areas contaminated with radioactivity. The MOE took on the task of unifying information about radiation and health effects across government ministries – bringing this together in a publication called “Basic Knowledge and Health Effects”. Pamphlets and comic books explaining radiation risk were also utilized.

The publications illustration provided explanation of the following topics:

- Radioactivity and environment;
- Radioactivity and food;
- Decontamination;
- Transportation of radioactive wastes contaminated with radioactivity.

As already mentioned, the MOE teamed up with municipalities to lend personal dosimeters to residents providing them with an opportunity to measure external radiation dose rates for themselves. Dosimeters were linked to a small GPS which allowed geographic data to be collected. This data is owned by the individuals and are not collected centrally. However, individuals could download an app that would allow them to display their monitoring data. The use of the devices meant that people were reassured by the actual doses measured.

Telephone helplines were established by the MOE in December 2011 to provide information and support on decontamination. These services were later reviewed and currently include separate public lines for general queries, e.g. about decontamination and the ISF. A total of 2,233 queries were received between December 2011 and March 2012. Calls reported suspected improper decontamination activities and misconduct by officials (government), contractors, and other agents involved in decontamination activities. The contents of calls were shared within the MOE on a daily basis to facilitate a prompt response. Over time, the number of calls declined to between 200 and 300 calls per year between 2013 and 2015.

The MOE also produced several 30 minutes, easy to understand, television programmes explaining various aspects of the decontamination project. For example, one of these set out to explain how radiation dose rates could be reduced by removing topsoil. The video was presented by a well-known Japanese comedian and television personality. This particular presenter was chosen because it was felt that he could get the message across better than a government official. The MOE also used two local radio stations to transmit information and highlighted progress on Fukushima revitalisation in local newspapers.

The MOE has also supported the Fukushima Health Management Survey with funding for research programmes [103]. The programme was managed by the Fukushima Medical University under the initiative of the Fukushima Prefecture. The aim was to protect and promote the long-term health of Fukushima residents. The project also included health surveys:

- Basic Survey: to record the movements of Fukushima residents from (11 March 2011) for the purpose of radiation dose estimation;

- Detailed Survey: thyroid ultrasound examination aimed at residents aged 18 years or younger;
- Comprehensive Health Check: aimed at residents of evacuation zones;
- Mental Health and Lifestyle Survey: for residents of evacuation zones using a survey questionnaire;
- Pregnancy and Birth Survey: for residents who were issued with a maternity and child health handbook.

In addition to the efforts of the central government led by the MOE, the Fukushima Prefectural Government and several municipal councils have taken forward their own initiatives to assist and support affected communities. For example, the Centre for Environmental Creation (CEC) in Miharu was set up by the Fukushima Prefectural Government in July 2016. The centre was given four key functions:

- Radiation monitoring;
- Research and investigation, including the dynamics of radioactivity in the environment, decontamination and waste management;
- Information gathering and dissemination;
- Education, training and interaction.

The community building, known as Commutan Fukushima, aims to disseminate information to facilitate understanding of ionizing radiation and awareness of environmental protection, recovery, and community revitalization. The centre demonstrated radiation safety and the decontamination process in interactive ways using cutting edge technologies, for example, a cloud chamber to visualize ionizing radiation and a 3D theatre.

6.3.3.1.Promoting dialogue among stakeholders

The MOE has supported counsellors and local government staff in addressing a wide range of residents' needs in the Fukushima Prefecture and neighbouring areas. The balance appears to have been weighted towards getting messages across to affected communities. Seminars and discussion groups have played an important part in this campaign.

For example, discussions have included the basics of ionizing radiation and risks, potential health impacts and guidance on how to manage the day-to-day exposure. These were delivered through the deployment of the counselling staff, medical practitioners and volunteers. Recognising a cultural trait that people may be reluctant to share their concerns, the size of discussion groups were kept deliberately small.

Non-profit organizations (NPO) such as the Society for Remediation of Radioactive Contamination in the Environment, supported local administrations and stakeholders in the impacted areas by providing technical expertise, organizing symposiums, and conducting research. These NPOs' activities were recognised as trusted sources of information to the stakeholders and provided remediation advice to the MOE based on expert observations.

TEPCO has also provided significant support to local and national governments. For example, seconding technical experts to work alongside and support officials and providing monitoring equipment.

6.4. THE IAEA–MOE MEETINGS ON STAKEHOLDER ENGAGEMENT CHALLENGES

This section provides a more detailed cross-check of key observations and feedback of the IAEA team across the four meetings between February 2016 and November 2017 and how they were considered by the MOE.

6.4.1. Being inclusive – age, ethnicity, vulnerable groups

The IAEA team explored the efforts taken by the MOE and local administrations to ensure stakeholder engagement was inclusive of different age groups and ethnicity and took account of the special needs of vulnerable people, for example with disabilities. This was achieved in part by providing tools and briefing on radiation risk for professionals who normally work closely with diverse communities. Hubs such as the Decontamination Information Plaza in Fukushima City became a focus for briefing and support to health professionals, midwives, care workers, teachers and voluntary organizations and charities working with disadvantaged groups. The centre also provided experts to support the Prefecture and municipalities to address questions raised by residents. The use of national and local television and radio networks also carried key messages to all sectors of Japanese society.

6.4.2. Social media

Social media such as SNS, Facebook, YouTube and Twitter were also recognised as powerful communication tools. These platforms are especially effective in reaching young people and specific online communities. Social media can also be an effective means of monitoring trends in public reaction and perception. The IAEA Team noted (second IAEA-MOE meeting, November 2016) that social media did not appear to have been used extensively in the recovery phase communications or engagement. Social media may also be a platform for misinterpretation, exaggeration, and misinformation. This may fuel public anxiety and concern or negative responses to advice from government and local authorities on protective measures. Social media engagement needs to be carefully managed to ensure misleading information is monitored and challenged.

6.4.3. Leaning from experience

At the second IAEA–MOE Meeting in 2016, the MOE highlighted the following stakeholder engagement challenges:

- The need to craft an engagement strategy to address the anxieties and concerns of people thinking about returning to areas contaminated with relatively high levels of radioactivity;
- With increasing numbers of people returning to former homes, how to strengthen risk communication messages and provide adequate health advice;
- How to manage public concern about thyroid cancer following the publication of research in the scientific literature;
- The need to maintain cooperation with international organizations such as UNSCEAR on aspects of health management and risk communication.

Recognising the challenges, the IAEA team noted the importance of learning lessons as the remediation efforts progressed. The team recommended that the MOE reviewed and assessed the effectiveness of stakeholder engagement in decision-making to extract the lessons learned. This message was also stressed at the fourth IAEA-MOE Meeting in 2017. Improved stakeholder engagement practices could usefully be implemented as evacuated areas were repopulated and remediation continues, with the aim of reaching the long-term clean-up goal.

6.4.4. Embedding stakeholder engagement

The MOE recognised the importance of stakeholder engagement as an essential part of the remediation process which was evident in all actions implemented by the MOE. The municipal authorities were responsible for remediation in the ICSA. The third IAEA–MOE Meeting learned of reports that the appropriateness of decisions adopted in these areas was being reconsidered by the stakeholders.

The accumulated experience of the municipalities with regard to community engagement and interaction with national government post-Fukushima illustrates the practical, logistical and coordination aspects of stakeholder-related issues in a major wide area remediation effort.

Consideration of specific approaches of the Japanese authorities by the international community will be appropriate and useful to analyse the impact of the implemented activities in relation to internationally adopted practices as well as to bring together recommendations of the social sciences community.

6.4.5. Building trust through effective leadership

The Fukushima Daiichi NPP accident damaged public trust in government institutions. The need to rebuild trust and understanding with communities through effective risk communication has been a persistent theme for discussion throughout the IAEA–MOE Meetings. The second and third meetings provided a unique opportunity to explore with Date City officials how strong, visible leadership in combination with effective engagement, enhanced trust and participation of communities in remediation efforts.

6.4.6. Lack of trust and building trust

The impact of lack of trust in government on the mental health of people living in areas affected by the Fukushima Daiichi accident has been investigated [104]. It was concluded that negative impacts on mental health become more serious after a nuclear accident and dedicated support services are needed in affected areas.

The exposure of communities to ionizing radiation is as much a social issue as it is a technical issue. Radiation raises unparalleled levels of fear among the general public. To achieve a deep understanding of the consequences of exposure to ionizing radiation, advanced knowledge of scientific and technical matters is needed. As is the case for other scientific fields, well-established principles and evidence will be contested. This may discredit experts, fuelled by the opinions of non-experts, who have the support of and empathy with the public.

Trust in official institutions will play an important role in the success of activities to remediate, revitalise and recover from the accident. However, trust will have been eroded by the accident itself, and by misinformation, rumours and confusion, as well as the difficulties people have in understanding ionizing radiation. This is compounded by perceived or detected problems in communication between different institutions and organizations. For example, in the case of Fukushima between:

- TEPCO and central government;
- TEPCO and the general public;
- Different levels of government;
- Between Japan and the international community.

Despite the efforts of the government to manage impacts on health, environment, the economy and normal living, it is likely that complaints of inadequate planning to deal with a nuclear accident and provision of information to affected communities and local authorities will always exist.

It has been observed that the criticisms levelled at institutions and officials managing a crisis seem to be much the same and are very familiar. So too, are the solutions adopted by the government. These include:

- Giving more emphasis to social dimensions, such as rebuilding and revitalizing areas affected;
- Improving transparency and accountability;
- Improving the way risk is communicated and enhanced education.

The key point is that mistakes made during the immediate response to a nuclear accident will decisively impact efforts to recover, restore and revitalize. In the context of Fukushima, steps to rebuild 'lost' trust were recommended in Ref. [105]. These include and are not restricted to:

- Greater transparency from TEPCO and the government;
- Greater accountability for the nuclear accident;
- More engagement with concerns of local communities;
- Continuing to improve understanding of ionizing radiation through education.

The Japan Atomic Energy Relations Organization (JAERO) also report on the reasons for distrust in government and the nuclear industry:

- Lack of information disclosure (nuclear industry 68.3%, government 62.5%);
- Insufficient preparation and management on safety (nuclear industry 60.4%, government 54.1%);
- Not speaking honestly (nuclear industry 59.8%, government 59.2%).

The lack of trust has a clear impact on the views and position of the population on the role of nuclear energy in Japan. In addition to the economic impacts, the primary impacts of the accident are social and psychological in nature. These will be more pronounced in the more vulnerable segments of society.

6.4.7. The co-expertise process

It has been raised in many times in the IAEA-MOE meetings that shortly after the Fukushima accident, there was an atmosphere of public distrust in government authorities and official institutions. Lack of trust in governmental organizations and officials (despite their qualifications and ethical conduct) is not something new.

Some communities decided to take matters into their own hands to better understand the situation and develop put together reports and other technical/scientific material by themselves and also sustained consultation with different experts. [106]. Although authorities were left out of these initiatives, radiological protection professionals were invited by local people to assist them with environmental monitoring and analysis of the results. Reference [106] provides examples of community activities, such as mapping the local contamination, monitoring internal and external exposures, decontamination works, and the monitoring of local foodstuff. By doing this, the authors suggest that local people managed to 'make radioactivity visible' and developed a better understanding of radiological issues related to environmental radiological conditions. Radiation experts also addressed questions and concerns raised by communities.

As a result, some professionals and experts have gradually engaged themselves with communities leading to what has become known as the 'co-expertise process'. It is possible that community engagement with experts, triggered by a motivation to better understand the radiological landscape in which they have found themselves living, has contributed to an emerging radiation protection culture where radiological literacy has improved.

The Kawauchi Village case study mentioned in Section 6.2.2.5 provides further demonstration of the co-expertise process at work in post-Fukushima recovery. This was a proactive intervention by staff from Nagasaki University to support a local community, rather than being initiated by the community. However, the following are good examples of Nagasaki University's co-expertise approach:

- Conducting surveys and reporting results;
- Explaining the findings of the radiological assessment and environmental monitoring (including sampling);
- Embedding a public health nurse in the community to provide advice;
- Engagement through public seminars and the classroom.

6.5. INTERNATIONAL PERSPECTIVES

This section provides a summary of international perspectives on stakeholder engagement and the wider social, political, and economic factors that are relevant to decision-making after a nuclear accident.

6.5.1. European Joint Programme

CONCERT is the European Joint Programme for the Integration of Radiation Protection Research under the Horizon2020 platform, and was the umbrella for nine projects: CONFIDENCE, LDLensRad, TERRITORIES, ENGAGE, LEU-TRACK, PODIUM, SEPARATE, VERIDIC and SHAMISEN-SINGS. Of these, TERRITORIES, ENGAGE and SHAMISEN-SINGS are relevant to the discussion of stakeholder engagement in the context of recovery of off-site areas affected by the Fukushima Daiichi NPP accident.

6.5.2. **TERRITORIES project**

The TERRITORIES project is "**T**o **E**nhance unce**R**tainties **R**eduction and stakeholders **I**nvolvement **TO**wards integrated and graded **R**isk management of humans and wildlife **I**n long-lasting radiological **E**xposure **S**ituations". The TERRITORIES project discussed "how social and ethical considerations can be integrated into radiological protection research and how to perform socio-economic analysis". The project also investigated the role of uncertainty management in decision-making processes for existing exposure situations. The following research undertaken within the scope of the TERRITORIES project is relevant to the post-Fukushima experience of stakeholder engagement.

The role of radiological protection experts and stakeholder involvement in the recovery phase of a nuclear accident has been examined [107]. It has been concluded that to achieve effective rehabilitation of living conditions, there is a need for a holistic approach. Rehabilitation of living conditions is a key priority but needs to be taken forward in combination with restarting agricultural activities and improving the attractiveness of affected areas for new investment and economic activity. Engagement with affected communities to understand barriers and incentives for rebuilding a new way of living is important for creating effective restart strategies.

The role of uncertainty[9] associated with radiation exposure in different scenarios was also studied [108]. One scenario involved long-term radiation exposure following a nuclear emergency. The starting premise was that people experiencing a crisis deal with different types of uncertainty. For example:

- Scientific communities deal with uncertainties related to data and are driven by methods, such as dose–response relationships;
- Decision-makers are faced with uncertainties related to the possible consequences of the event, the options for decision and public reaction;
- People affected by a radiological emergency tend to be sceptical about experts' position on issues related to specific risks associated with exposures to ionizing radiation.

When creating opportunities for stakeholder engagement, there is a need to be aware that uncertainties diverge (and potentially broaden) from scientists to decision-makers, and to laypeople. This means that in a two-way conversation, it is important to speak each other's language for communication to be successful. Noting that the main goal of uncertainty communication is to get the public to understand, trust and make effective use of the information provided, in Ref. [108] it is recommended that more attention be paid to information receivers (in this case decision-makers and laypeople) to understand what information they want and need to make informed decisions. When scientific uncertainty (radiation data) meets everyday uncertainty, scientific logic diverges, causing problems with communication and understanding. The authors argue that to bridge the gap between different perceptions and definitions of uncertainty among different actors, the creation of mutual understanding, as well as building trust amongst the actors is necessary.

6.5.3. The ENGAGE project

ENGAGE (Enhancing Stakeholder Participation in the Governance of Radiological Risks) investigated which formal or informal demands and expectations for the engagement of stakeholders exist, and how these are translated into practices at national and local levels. It highlighted what the standing challenges are and suggested which new research and development avenues might be pursued to address these challenges.

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[9] The authors recognize that there is no agreement regarding definitions of uncertainty, which is mainly defined based on its sources, types or categories rather than by its meaning.

Three ionizing radiation exposure scenarios were addressed in terms of stakeholder engagement:

- Medical exposures to ionizing radiation;
- Nuclear emergency preparedness, response and recovery;
- Exposure to indoor radon.

Regarding 'Nuclear emergency preparedness, response and recovery', an important conclusion from the project is that stakeholder participation cannot be assumed to be stakeholder communication. Neither is it a tool for decision making. Both are an intrinsic part of the decision-making process. In conclusion, the project makes some important recommendations, including the need to [109]:

- Broaden the motivation for stakeholder engagement in emergency planning response and recovery (EPR&R);
- Broaden the scope of participation in EPR&R;
- Recognise the role of informal stakeholder engagement in EPR&R;
- Integrate stakeholder engagement EPR&R plans and policies;
- Establish strategies for continuous, two-way communication about emergency and recovery planning, tailored to specific stakeholders from both local and wider areas;
- Develop a strategy to develop a radiation protection culture in the preparedness phase.

6.5.4. Nuclear Emergency Situations - Improvement of Medical and Health Surveillance - SHAMISEN

The SHAMISEN Project critically reviewed current recommendations and experience of dose assessment and dose reconstruction, decisions related to evacuation orders, long-term health surveillance programmes and epidemiological studies. The project highlighted the need for a holistic approach to assist decision-making in a nuclear emergency. Building on this premise, emergency planning and preparedness could be improved greatly by giving attention and focus to activities that support community rehabilitation and recovery, including remediation.

6.5.5. Decision-making for nuclear emergencies: A holistic approach

The conclusions from the projects noted above, though valid, are not new. The IAEA report IAEA NW-T 3.5 "Communication and Stakeholder Involvement in Environmental Remediation Projects" [110] published in 2014, includes a section on non-technical aspects of the environmental remediation processes. This includes finance, human resources, project management and involvement of the public. The authors recognised the significance of these factors in the decision-making for remediation projects.

Members of the public (and sometimes their political representatives) may have personal and diverse views on radiation risks. Social and political factors, unrelated to radiological protection, usually influence the final decision on remediation. Whilst science provides decision-making tools, other social, political, and economic concerns need to be considered. Therefore, the participation of relevant stakeholders, rather than radiological protection specialists alone, will be an integral part of the overall process. This is particularly relevant when people live in contaminated areas after a nuclear accident or radiation emergency.

IAEA NW-T 3.5 [110] stressed the need for individuals to regain control of their situation. The report also recognised five levels of stakeholder involvement:

- Communication;
- Listening;
- Consultation;
- Engagement;
- Partnership.

The report concludes by offering pointers for stakeholder engagement in environmental remediation - including the notion that “no single solution fits all”. Local, social and political boundary conditions will play a key role in the definition of the optimal approach in the situation under consideration.

6.5.6. Stakeholder engagement as an ongoing process

GSG-15 [91] sets out the position of IAEA Member States on the involvement of stakeholders, referred to as ‘interested parties’. Stakeholder involvement is recognised as key to the successful implementation of remediation and should take place throughout the entire process including the post-remediation phase.

GSG-15 [91] notes that insufficient involvement could have a strong negative effect on individuals, and that the involvement of stakeholders is key to the successful implementation of remediation and should continue throughout the entire process - even in the post-remediation phase.

Paragraph 2.53 of GSG-15 [91] states:

> “Interested parties should have a role in contributing knowledge and information to the remediation process. The role of interested parties, such as members of the public, the responsible party, the regulatory body and/or other relevant authorities involved in the remediation is to exchange information in an ongoing dialogue to help ensure that well-informed decisions are made. Representatives of interested parties should have the opportunity to express and discuss their positions, expectations, and views regarding the remediation. This will facilitate the development of a mutual understanding and meaningful involvement in the decision-making process regarding the planning and implementation of remedial actions.”

6.5.7. International perspectives: conclusions and next steps

There is broad consensus across the international community that the involvement of stakeholders in decision-making contributes significantly to the successful implementation of sustainable remediation of contaminated sites. Integration of stakeholder engagement in remediation policy and strategy can be seen as a priority for authorities responsible for shaping national frameworks for post-accident remediation. The international community may wish to continue to create opportunities to share learning, experience and research from stakeholder engagement in environmental remediation.

6.6. LESSONS LEARNED

In this section, the lessons learned with stakeholder related issues are provided in different thematic areas.

6.6.1. Legislation, policy, strategy and plans

GSR Part 1 (Rev. 1) [89] makes it clear that well-developed legal, regulatory and policy frameworks are a prerequisite for effective remediation. IAEA NW-G-3.1 [90] recommends that policy, strategy and plans are also in place as part of planning for accident situations: these set out how public participation in decision making will be managed. Preparing remediation frameworks away from the pressures of post-accident response means that remediation is more likely to start on the right track, progress without delay, involve stakeholders early and result in successful outcomes.

6.6.2. Get ahead of the game

In the days and weeks immediately after the Fukushima Daiichi NPP accident, public knowledge of radiation risk and health consequences was minimal. Repeated and confusing explanations of the impact of radiation on health caused anxiety and eroded public trust in the government. Later, as national and government authorities turned their attention to remediation, the need to regain and rebuild levels of trust added a further significant challenge. Investing time and resources to deliver public health messaging effectively right from the start and maintaining the confidence and trust of the public through the transition to recovery will benefit long term remediation projects. This is a key element of national and local stakeholder engagement planning and preparation for nuclear emergencies.

6.6.3. Take a holistic approach

The Fukushima Daiichi NPP accident caused major disruption of infrastructure and gave rise to economic and societal losses and a range of acute, chronic and indirect impacts. Recovery management goes beyond the need to understand the radiological implications for people, health and well-being. It needs to include strategies for returning the functionality of whole communities by restoring the environment, infrastructure, business, employment and public services. Setting priorities for recovery will involve balancing many of these factors and effective dialogue between radiation protection experts, policymakers and stakeholders. Partners in this process need to understand the dependencies between proposed risk reduction efforts and avoid developing remedial measures in isolation.

6.6.4. How will decisions be made as a result of stakeholder participation?

Recovery strategies need to be clear about the extent to which post-accident remediation will be driven by or informed by stakeholder views. Those facilitating stakeholder engagements need to be prepared to set out what is feasible, affordable, as well as technical and other constraints to implementation of options preferred by stakeholders. For example, they need to understand that the remediation process often involves a balance between reducing exposure risks and increasing waste volumes.

6.6.5. Clarifying roles and responsibilities

National and local governments need to clarify roles and cooperate when explaining the risks associated with environmental contamination and remediation proposals. The international guidance described in Section 6.2.2.1 recommends clarity on roles and responsibility for the coordination of stakeholder engagement. Education about radiation and health effects is a matter for the national government, not individual departments. The aim is to provide one version of the radiation and health message and promulgate it in the context of ministerial department interests. For example, food and water, transport, trade and industry, education, culture and sport.

6.6.6. Duration of the remediation activities

It is important to be realistic about how long remediation activities will take to be implemented. Managing stakeholder expectations is very important while being clear and transparent about the progress on decontamination and reconstruction.

6.6.7. Delivering information and support to affected communities

Continuous, consistent, community-wide support on technical and scientific aspects of remediation cannot be delivered by municipal authorities or counselling services alone. This support requires national and municipal coordination in collaboration with community professionals and radiation protection experts. Dedicated facilities, accessible to service providers and the communities affected need to be planned and resourced as part of planning and preparation for recovery.

Non-profit organizations and volunteers have an important role to play in supporting engagement with affected communities providing a diverse range of operational support skills and services, including in some cases, radiation protection expertise. Authorities need to recognise this capability, seek to build relationships in advance, agree on how to work together and be ready (capability and resource) to work with voluntary organizations when the time comes.

6.6.8. Co-expertise approach

The cooperation between residents, specialists and community professionals with the support of a local and national government can enhance the pace and effectiveness of recovery and create a sense of ownership and purpose for those involved. The collaboration between Nagasaki University and the Kawauchi Village illustrated key elements of the co-expertise approach. A public health nurse and satellite office of the university embedded in the community provided access to advice to address concerns and practical support on monitoring and radiological assessment. This improved the radiation protection literacy of the community and facilitated an emerging radiation protection culture.

6.6.9. Stakeholder engagement

The Fukushima Daiichi NPP accident has highlighted the negative impacts of misinformation and rumour on efforts to support community rehabilitation and revitalization. Unchecked, this has the potential to influence behaviours that undermine efforts to support community recovery. For example, the ill-informed belief that evacuees were ‘infected’ with radiation, impacted their acceptance and integration into receiving communities. Rumours about the health impacts of contaminated agricultural products originating from Fukushima Prefecture were also a concern for food producers and suppliers working to re-establish their business after the accident

6.6.10. Dispelling rumours and misinformation

As part of the planning for post-accident recovery, authorities need to be ready to:

- Monitor public reaction, perceptions, and trends to identify sources of misinformation with the potential to undermine public confidence.
- Convey evidence-based, accurate information and advice to counter misinformation and rumour through effective stakeholder engagement and dialogue. Successful outcomes are more likely to be achieved if those involved in delivery have good knowledge of their

communities, (doctors, teachers, community nurses, teachers) supported by radiation protection specialists.

6.6.11. One size does not fit all

The following presents key factors to consider in shaping stakeholder engagement initiatives in the context of remediation and recovery.

- Stakeholder needs: These will vary with location, available support networks (family and friends), socio-economic status, education, disabilities and vulnerabilities, age, gender, ethnicity, cultural factors. Levels of understanding about radiation risk, environmental contamination and remediation need to be considered.
- Recent stakeholder experience of the crisis: What are the impacts? How have they been affected? How is the situation making them feel? How will this affect engagement?;
- Maturity of community engagement: Is this a new initiative or is it well-established?
- Objectives of stakeholder engagement: Is it to understand concerns? Elicit views? Impart information? Educate and engage? Make, Shape and influence decisions?;
- Message: Is it basic or technical? Can the message be made easier to understand? How may the message be best presented? Consider media and formats. Who is best placed to listen to community concerns and deliver the message? Consider levels of audience trust and familiarity with the messenger.
- Lessons from other relevant stakeholder engagement initiatives.

6.6.12. Adapt and flex

Public information needs to change as the post-accident recovery and remediation efforts progress. Authorities need to adapt stakeholder engagement activities from the explanation of radiation concepts to developing a radiation protection culture. This means strengthening advice and awareness-raising functions of local governments and professionals who have gained the trust of residents and communities.

6.6.13. Uncertainty – a potential barrier to effective engagement

People have different perspectives on uncertainty. Scientists see uncertainty in the context of data and methods. Decision-makers are concerned with the consequences of options and public reaction to their decisions. The public may be uncertain about whether experts and decision-makers can be trusted. These perspectives may impact the effectiveness of communication between key players in the recovery and remediation process. Facilitation of stakeholder engagement needs to recognise these different perspectives of uncertainty and bring parties to a position of mutual understanding.

6.6.14. Continuous improvement

Recovery is a long-term process: therefore, relevant authorities need to plan to measure and assess the effectiveness of stakeholder engagement initiatives. Allocation of time and resources are important aspects to be addressed. The knowledge about stakeholder engagement initiatives needs to be captured i.e. what went well and what could be done differently to improve outcomes. Learning as one goes along (See Section 7) and the application of lessons learned to the next steps for recovery management is crucial. Therefore, the creation of opportunities to share good stakeholder engagement practice needs to be carefully considered as much as how the learning can be used in the planning for future emergencies.

7. KNOWLEDGE MANAGEMENT IN SUPPORT OF REMEDIATION OF AREAS AFFECTED BY NUCLEAR OR RADIOLOGICAL ACCIDENTS

7.1. INTRODUCTION

This section deals with the topic of Knowledge Management (KM) for supporting remediation in off-site areas affected by nuclear or radiological accidents, not only in view of the Fukushima Daiichi NPP accident but also in a more general sense by highlighting diverse efforts that have been made in the past[111]. The purpose is, on the one hand, to emphasize the valuable initiatives that have been promoted in conjunction with the Fukushima accident and, on the other hand, to put these efforts into a more general framework by compiling KM initiatives that have been supported before. Furthermore, due to its novelty in the field of remediation, the topic of KM is introduced generally. Hence, after some motivational words on the added value of KM in this specific area, the first part of this section is dedicated to the general idea of KM and, since KM aims at improving future decision-making capabilities, to discussions on the distinctive challenges of post-accident situations with regard to decision-making and specifically concerning KM. Furthermore, for putting KM initiatives that are related to the Fukushima accident into context, KM tools, approaches, and practices promoted before this accident are presented. The second part of this section is dedicated to KM within the context of the Fukushima Daiichi NPP accident and associated KM initiatives, including related KM research that has been triggered by the accident as well. The findings presented so far are summarized in the third part of this section.

7.2. THE INPUTS FROM IAEA–MOE MEETINGS ON KNOWLEDGE MANAGEMENT

The topic was brought to the IAEA–MOE discussions during the second meeting. As already explained in this report, decontamination work has been implemented to a great extent by means of contractors, because the kind of activities put in place resembled those of ordinary civil construction operations. In the second IAEA–MOE meeting, experts were informed that throughout the remediation works, individual contractors were developing their own approaches to document their knowledge and experiences. In addition, they have formed a council to exchange information amongst the member companies. It was reported that the council was founded by TEPCO and had — at the time of the meeting in 2016 — a membership of 67 private companies. Through regular meetings and workshops, the companies have been exchanging knowledge and experience associated with the remediation.

It has been identified by the experts that mechanisms to capture tacit knowledge were needed. It was suggested that the MOE could consider compiling knowledge and experience amongst municipalities and provide for the sharing of such information to improve the remediation efforts in Japan. At the international level collected information was considered invaluable input in case similar activities might be needed in the future.

Attention was called to the fact that information and field data would need to be adequately detailed to be useful e.g. field conditions at the time of decontamination could influence decontamination effectiveness and should be specified to provide information on the efficiency and possible challenges met by decontamination workers. Knowledge capture would also need to cover a range of topics such as strategic oversight, management and coordination, interfaces between organizations, the efficacy of remediation techniques, communication with and engagement of interested parties, and others.

This report addresses, in part, the recognized need to retain and share the experience and the knowledge obtained during remediation related activities with the international community, while enhancing the understanding of different stakeholders on the different aspects related to environmental remediation. The scope of this section is to focus on these aspects and propose a mechanism that can make the management of knowledge in the remediation phase of a nuclear or radiological accident more efficient, while also contributing to improved decision-making.

With the above in mind, the objectives of this section go somehow beyond what was intended with the others. More than going through the efforts of the MOE in managing knowledge acquired with the remediation of the areas affected by the releases of radioactive materials, an attempt is made to demonstrate the role KM can/has to play in remediation activities. It is also aimed at raising awareness within the remediation communities on the importance of KM, and to present current research and application examples for providing practical guidance and disseminating relevant experiences and lessons learned.

In particular, KM elements and tools are presented to meet the requirements and distinctive challenges faced in the remediation of off-site areas affected by nuclear or radiological accidents. Information technology (IT)-based systems supporting KM efforts are promising for supporting decision-making processes, especially approaches for reusing experiences from previous events to be available and embedded in a decision support method. Suitable management options based on similar historical events and scenarios could be identified to support disaster management.

It needs to be recognized that solutions that have been applied in a specific situation may not be totally applicable in a different context, i.e., ‘no one solution fits all cases’. Regardless of this, there will always be valuable lessons learned with the remediation of areas affected by nuclear or radiological accidents that will help in framing the implementation of remedial actions in case of a new accident.

7.3. MOTIVATION

Large-scale disasters are characterized by severe disruptions of the society’s functionality and adverse impacts on humans, the environment, and the economy exceeding society’s capabilities to cope using its own resources [112]. Nuclear disasters pose increased demands on decision-makers, due to the potential long-term and transnational health risks for humans and environmental contamination. Decision-making is challenged by a great uncertainty in the key information, especially in the early phase of an accident, and, particularly during the later phase, by a multitude of possible measures and stakeholders with partially competing objectives that need to be respected. Concerning the latter, pressure comes from not only the communities living in the affected areas but also from society as a whole. A series of decisions need to be made and coordination amongst all the relevant stakeholders is of fundamental importance. This section focuses on decisions concerning remediation and hence “any measures that may be carried out to reduce the radiation exposure due to existing contamination of land areas through actions applied to the contamination itself (the source) or the exposure pathways to humans.” [3] Long-term remediation refers to the period that covers the management of an existing exposure situation and the long-term recovery operations after the emergency has been declared to have ended, whereas control of access, decontamination etc. may also be applied in the transition phase to allow for the progressive lifting of protective actions [113].

With regard to environmental remediation actions, the existence of policy and strategies help in defining the basic principles underlying the decisions to be made, indicating the responsibilities of different organizations, and establishing proper communication and engagement channels for different stakeholders in the decision-making process. Guidance material (e.g. handbooks) contains information that helps to put in practice specific actions to address the policy and strategies that have been defined. In respect of implementing remediation projects, lack of relevant information and gaps in the required knowledge may result, among other potential risks, in delays in the implementation, increased costs, and compromised safety. In general, the ability to make safe decisions and actions can be impaired by knowledge gaps or loss, and the nuclear sector would profit from "appropriate methods and supporting technology … to establish and manage nuclear competencies, information and records, work processes, analysis and verification techniques, and the interpretation of data" [114]. In this capacity, KM is one of the promising disciplines for implementing remediation projects smoothly, encompassing elements such as:

- Sharing and capitalizing on good remediation practices and lessons learned;
- Assuring the competence of personnel involved in remediation activities;
- Transferring knowledge to future generations.

7.4. KNOWLEDGE MANAGEMENT AND PREVIOUS ACCIDENTS

The origin of KM as a field of study can be traced back to the early 1990's and can be understood as a practitioner-based, substantive response to real social and economic trends such as globalization, ubiquitous computing, and a knowledge-centric view [115,116]. Being shaped by different disciplines such as economics, sociology, philosophy, and psychology as well as practices such as information management, quality movement, and human factors e.g. human capital movement [115], KM can be regarded as a complex and multi-faceted concept

7.4.1. Drivers of knowledge management

Drivers of KM coming from economics refer to learning mechanisms and strategies and their effects on organizational effectiveness and performance. Sociology contributes to macro and micro perspectives to KM and concerns social facts and how people actually (re-)use or share knowledge. Philosophy and psychology concern the differentiation between tacit and explicit knowledge and analyse how and why people learn, forget, ignore, act, or fail to act [117] . Information management deals with information issues in respect of valuation, operational techniques, governance, and incentive schemes and contributes to the differentiated view on knowledge, especially in terms of handling different kinds of knowledge. Furthermore, KM uses analysis and improvement techniques of the quality movement to make knowledge visible and develops knowledge processes, process owners, and governance structures. In addition, building on ideas of human capital, KM emphasizes and promotes the value of human capital, especially group knowledge and social capital.

7.4.2. Defining knowledge

The notion of knowledge is strongly linked to experience and learning and is hence of a dynamic nature [118], being distinguished from data and information [119] Whereas data are objective facts that become information when meaning is added, knowledge can be understood as "a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information" [119]. KM can be defined as "the practice of selectively applying knowledge from previous experiences of decision making to current and future decision-making activities with the express purpose of improving the organization's effectiveness." [120]. Knowledge can be differentiated according to tacit and explicit knowledge [117]. Tacit knowledge, being in the knower's mind, can be made explicit by sharing, explaining, recording, or documenting to create a knowledge artefact [117].

Knowledge transfer in an organization refers to passing tacit and explicit knowledge to each other, which can be assisted by IT-based systems [116]. Four modes of knowledge transfer and creation are proposed, converting tacit and explicit knowledge into each other [121] emphasizing a common understanding of the knower to the user of knowledge [120]. This commonly known SECI model

(Socialization – Externalization – Combination – Internalization) of knowledge dimensions explains how tacit and explicit knowledge can be converted into organizational knowledge and is hence a model of knowledge creation [121]. The successive processes of socialization (tacit to tacit by social interaction and sharing experience, respectively), externalization (tacit to explicit by publishing or articulating tacit knowledge into explicit concepts with the help of e.g. metaphors, analogies, and models), combination (explicit to explicit by e.g. organizing and integrating knowledge by means of e.g. computerized communication networks or databases), and internalization (explicit to tacit by knowledge application and learning by doing, respectively, possibly being accompanied by creating documents or manuals built upon experiences), raises individual knowledge spirally to higher organization levels (see Fig. 32). This model appreciates the dynamic nature of knowledge and knowledge creation [121].

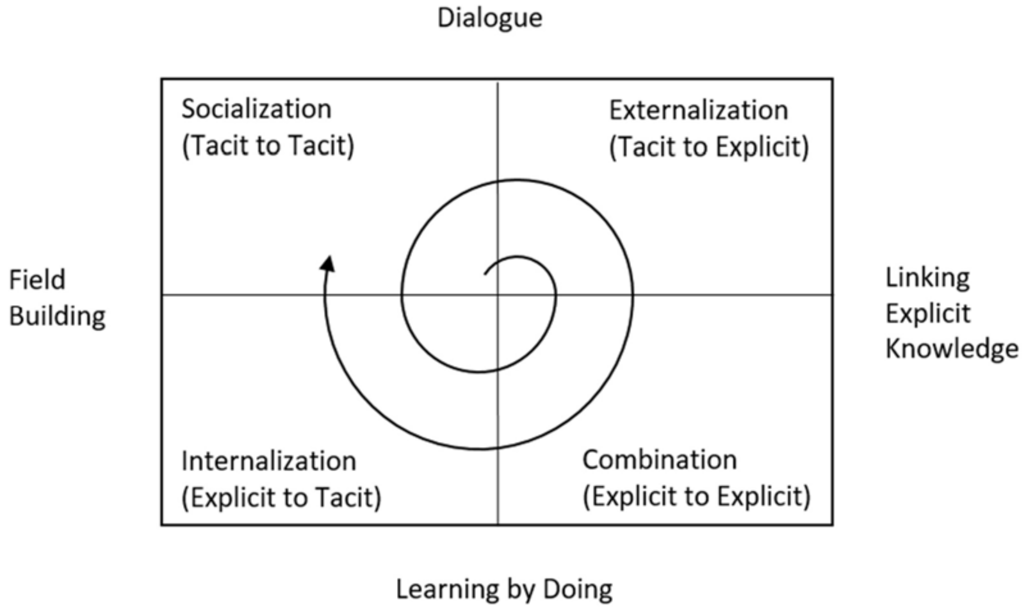

FIG. 32. Knowledge spiral (reproduced from [121] with permission).

7.4.3. Knowledge management systems-KMSs

Being mainly resided in commerce and industry, the value and power of knowledge creation and sharing across an organization is acknowledged by practitioners of different disciplines, e.g. computer science, organizational science, or communication [118]. KM is a multidisciplinary field drawing from many subjects and various definitions of KM exist depending on discipline and country [122]. However, reduced to its basic characteristics, KM is largely regarded as a process of creating, storing, retrieving, transferring, and applying knowledge being supported by knowledge management systems (KMSs) [123]. KMSs are IT-based systems comprising different technologies to enable KM processes of knowledge creation, acquisition, sharing, evolution, and transfer such as knowledge-based systems, document management systems, semantic networks, object-oriented and relational databases, decision support systems, expert systems, simulation tools, groupware, and intranets

A comprehensive KMS integrates different functionalities for handling knowledge in a structured and contextualized manner and supports knowledge creation, construction, identification, capture, acquisition, selection, valuation, organization, linking, structuring, formalization, visualization, distribution, retention, maintenance, refinement, evolution, access, search, and application aiming at supporting the dynamics of organizational learning and organizational effectiveness [124].

7.4.4. Advantages of knowledge management systems

The importance of KM resulted from a confluence of trends in the 1990s such as business process reengineering, technology, the explosion in content, information, and knowledge due to the rapid growth of the internet and corporate intranets, warehouses, and databases as well as better management of human and intellectual capital [116]. Knowledge provides a sustainable advantage to companies since, in contrast to material assets, knowledge assets increase with use supporting the potential for new ideas [119]. Furthermore, the use of appropriate KM strategies supports businesses in learning critical knowledge for enhancing crisis management, where different strategies are applied in different phases of a crisis [125]. Besides emphasizing the importance of learning and utilizing knowledge of past experiences for better managing similar future crises as well as technologies for facilitating KM practices during a crisis, operational issues of KM such as finding and utilizing appropriate knowledge for enhancing strategic and policy interventions during crises, need to be investigated in more depth. In this connection, several KM strategies being categorized according to different 'schools' can be identified [114], as follows:

- Systems schools: Creating and codifying knowledge and capturing and storing knowledge of individuals in knowledge repositories. Here, computer systems capturing, storing, organizing, and displaying knowledge gained from expertise and experience keep the initiatives running. In this connection, content validation and incentives to provide knowledge are crucial.
- Cartographic school: Mapping organizational knowledge and hence record and disclose knowledge owners. IT particularly helps to connect people and locate knowledge sources. Again, an incentive to share knowledge as well as networks to connect people are crucial.
- Process school: Equipping people with knowledge for effectively performing their tasks. Management processes especially benefit from decision-relevant information as well as contextual and best-practice knowledge. The supply and distribution of knowledge and information may not be restricted, and IT can promote knowledge sharing in terms of e.g. shared databases.
- Commercial school: Managing knowledge property and promoting the organization's capacity for realizing the economic value of its knowledge assets. Specialized teams as well as an institutionalized process, are critical success factors.
- Organizational school: Designing organizational structures or inter-organizational networks for connecting knowledge owners and especially sharing knowledge. In this connection, IT provides means to connect people and pool knowledge, also on the inter-organizational level, which might be beneficial for decision-making during crises. Knowledge intermediaries may influence success.
- Spatial school: Encouraging socialization as means for knowledge exchange. For instance, regular face-to-face meetings facilitate knowledge sharing during crises;
- Strategic school: Raising consciousness about value-creating possibilities when regarding knowledge as a key resource.

These different schools may help to identify and shape knowledge management initiatives, also by highlighting the potential contribution of IT-based systems.

Within the disaster management field, KMSs is suggested to capture and re-use specific crisis response knowledge to support decision-making [126]. Decision-making concerning appropriate measures during and after disasters can be demanding and complex owing to a highly dynamic environment, a limited time frame, uncertainty, and the presence of multiple stakeholders with possibly competing objectives [127, 128]. KMSs can help to focus and manage decisions, and lessons learned and understanding of good solutions in given situations help decision-makers to be prepared with workable plans [126]. Hence, "KMS enables the collection, retrieval, dissemination, and storage of the right knowledge to be used in the right place at the right time [126]." To enable realization, it is important to be aware of the challenges decision-makers face in post-accident situations as have been experienced in the course of the Fukushima Daiichi NPP accident. In the following sub-sections, some of the advantages of KM with reference to the issues of uncertainty, waste management, and stakeholder engagement are highlighted.

7.4.5. Post-accident situations decision-making and knowledge use

Nuclear or radiological accidents, depending on their magnitude, can cause severe disruptions in society's functionality and adverse impacts on humans, the environment, and the economy. They can have a great impact upon residents' life not only in the vicinity of the accident site but also in areas not necessarily directly related to the accident. A typical example of such influence is the financial damage caused by harmful rumours or misinformation.

As a result, following a severe accident, there is likely to be a sustained period of general turmoil frequently accompanied by acute time pressure. In times of crisis like this, decision-making can become a very complex endeavour. This is further complicated by the lack and uncertainty of information that would be required to enable a robust decision-making process for demarcating zones of contamination, determining the necessity and extent of evacuation and, ultimately, selecting decommissioning and remediation strategies and approaches. Furthermore, especially in the later phase of an accident, multiple stakeholders with possibly competing objectives enter the decision-making process and numerous possible management options exist of which appropriate ones need to be selected and then combined in a management strategy.

As could be seen in Fukushima, trials were conducted to choose appropriate technologies such as experimental and field-based demonstration projects that have been carried out to decide upon appropriate remediation measures, leading to accrued experience. The lack of experience is a very crucial issue as well as the difficulty to apply guidance and lessons learned from planned situations to severe accident scenarios.

Furthermore, and as could be experienced after the Fukushima Daiichi NPP accident, the public were sensitive to environmental issues related to decommissioning and remediation and the siting of waste storage. The possibility of waste storage is especially crucial when deciding on remediation measures. In this respect, when utilizing experience, one may only refer to strategies that are based on the same or at least similar frame conditions.

The three issues of lack of knowledge and uncertainty, waste management, and stakeholder engagement are further amplified below.

7.4.5.1.*Lack of knowledge and uncertainty*

Uncertainty in the context of decision-making is naturally connected to blocked or delayed action for decision-makers; the situation, the outcome, and the alternatives are uncertain, resulting from incomplete information, insufficient understanding or undifferentiated alternatives [129]. The authors state that one may (i) reduce uncertainty by collecting additional information, deferring decisions or extrapolating with statistical methods, making assumptions or even predictions and scenario-building, respectively, or react beforehand by controlling the source of variability; (ii) acknowledge uncertainty when evaluating options or completely avoid uncertainty by preferring clear outcomes; (3) to suppress uncertainty by denial or rationalization. Regarding uncertain information, one may further distinguish between missing, vague, and probabilistic information. Regarding probabilistic information, probability values quantify the correctness of a value. Incomplete information relates to missing values and information gaps. This distinction is important when it comes to discussions on how to handle uncertain information.

The many different types of uncertainties inherent in the management of a nuclear or radiological emergency can be grouped into those relating to our knowledge on the external world, the models and techniques for analysing risks and possible interventions in an emergency, and those that are introduced by emergency managers, experts, and stakeholders [119]. The authors state that lack of knowledge refers to, for instance, meteorological conditions, dispersion and deposition models, human behaviour, or health impacts owed to e.g. a lack of data or little consent among experts on the current situation or modelling approaches. Furthermore, uncertainty refers to modelling and analysis errors caused by imperfect algorithms or how the model fits reality. In addition, uncertainties in decision-making may arise from ambiguity and lack of clarity concerning some wording or visualizations, conflicting stakeholder priorities, or concerning the depth of modelling.

Each type of uncertainty needs to be carefully respected in the decision-making process where judgement and thoughtful deliberation, supported by sensitivity and multi-criteria analyses, are one way for resolving them [120]. A lack of knowledge and the significant uncertainties on the conditions of nuclear or radiation facilities and surrounding affected areas after a severe accident may be due to difficulties associated with extensive and hazardous data acquisition and are major factors that undermine post-accident activities.

Information on deposition is crucial to guide follow-up actions. Surveys of the potentially affected off-site areas are ideally to be undertaken through a combination of aerial, static, vehicular and walkover surveys, thus allowing estimates of dose rates, accumulated doses, and levels of soil contamination to be mapped out. Measurements in houses and other structures are likely taking place depending on the scale of the event. Mathematical models help to make predictions on the contamination pattern and also on the development of contamination with time. The living habits of the people in affected areas are also important. The use of individual dosimeters helps in providing a clearer picture of the doses members to the public.

Uncertainties in relation to off-site conditions and the evolution of contamination can hinder the definition of specific actions to be implemented during post-accident activities requiring as much reliable data as possible. However, preparations to counter all the uncertainties listed above that challenge decision-makers need to be made in advance and continuously. In this connection, KM initiatives may not only help to generate and preserve knowledge but also to make uncertainties visible, promote an exchange of knowledge and values, and further support a mutual understanding of all the actors involved in the decision-making process.

7.4.5.2. *Waste management*

Experience from recovery following past accidents shows the common issue of large amounts of waste generated very quickly, as well as complex compositions of waste in contrast to normal operational or decommissioning waste streams [130]. Additional challenges are a high level of concern from the public, technical difficulties in respect of characterizing and managing waste, the capabilities of the existing decision-making and regulatory framework, establishing efficient and effective management, and communicating information and activities. Furthermore, waste management activities are particularly interdependent on other response and recovery decisions.

As was the case after the Fukushima Daiichi NPP accident, the general public is sensitive to the remediation of off-site areas after a major accident, especially the challenges posed by the management of large amounts of radioactively contaminated materials produced through decontamination activities e.g. contaminated soil as well as from on-site activities such as a large amount of contaminated cooling water. The siting of disaster debris encountered strong opposition from local residents and/or communities [131]. The author states that communicating risks, costs, and benefits and a trustful relationship between the government and the public are essential to gain public acceptance and promote public understanding concerning waste management issues. Furthermore, enhanced recommendations may be generated by investigating different scenarios and cautious sharing and generalizing to similar frame conditions are possible. KM initiatives may help to generate knowledge to be made readily available when needed.

7.4.5.3. *Stakeholder engagement*

In general, following a severe accident, stakeholders' involvement can be very complex and intense where types of involvement range from informing and educating, gathering information, consulting, building consensus to the partnership. It is of utmost importance that all relevant stakeholders are engaged at an early stage to ensure participation and coordination in the decision-making process. Also, following the Fukushima Daiichi NPP accident, there was at some point, as described in the previous section, a lack of targeted communication with the public, which generated a general climate of mistrust in government radiation data.

The success of remediation projects is driven by the fact that stakeholders take responsibility for the remediation problem and can identify with the concept solution being reasonable for them. In general, timely and appropriate communication with stakeholders strongly affects success in crisis management [126]. During implementation, it is very important to coordinate the many organizations that may be involved in the deployment of technologies. While ideally knowledge is gathered and maintained at the level of the problem holder, different organizations engaged in the activities could bear divergent commercial interests or hold intellectual property rights that hinder their readiness in sharing acquired knowledge.

Public involvement through dialogue with governmental organizations and operators is very important and is critical when securing a storage site for the waste generated from both decommissioning and remediation works. The progress of stabilization and clean-up activities as the broad potential impacts of the accident are of course issues of concern to the public, along with any decisional matter that may affect people's lives. Communication to raise correct understanding of radiological effects based on scientific bases is essential to address concerns and misconceptions of the public. Central and local government and operators need to provide timely and sufficient information on environmental contamination, remediation strategy and plans, including storage of contaminated materials, and potential radiological consequences, which could be supported, for instance, by various KMS tools.

7.4.5.4. *Decision contexts and their implications*

In the framework of nuclear and radiological accidents, decision-making may be embedded in the known, knowable, complex as well as chaotic space possibly evolving into any of the others. Cause and effect are understood and can be predicted in the known space, can be identified with the help of enough data in the knowable space, maybe explained after the event in the complex space and are not recognizable in the chaotic space [132,133]. With reference to the different types of knowledge, explicit knowledge and hence knowledge that can, for instance, be encoded in a dispersion model, relates mainly to the known and knowable spaces whereas tacit knowledge and skills, expertise, and values respectively, relate more to complex and chaotic spaces where understanding is limited [132]. KMSs considering explicit and tacit knowledge, need to comprise flexible data and information management systems and collaborative working tools, particularly to share and work on materials together as well as support the maintenance of public and stakeholders trust and risk communication. Judgement building and collaboration are especially important for respecting social, political, and economic aspects in decision-making.

However, even if accidents may evolve into the chaotic space, that goes beyond current understanding and experience, in a way that decision support may not be analytical, similarities and experience accumulated may constitute a basis to build on further understanding, making the preservation of knowledge on past events an asset.

7.4.6. The role of tools, practices and approaches developed prior to the Fukushima Daiichi NPP accident

The Chernobyl accident, which occurred on 26 April 1986, affected large areas in Europe and in particular the three former USSR Republics of Ukraine, Russia and Belarus, as well as Norway. The extent of the accident consequences raised awareness of the difficulties inherent in managing the accidental and post-accidental impacts of such an event. It became clear that every lesson should be learned from the accident to analyse its impacts on the lives of the affected populations. One year after the Chernobyl accident, the radiological accident in Goiânia took place. Obviously, it did not have a similar magnitude to the Chernobyl accident, yet it did cause a lot of distress for the society with national repercussions. The Three Mile Island (TMI) accident in 1979 further initiated KM activities in terms of compiling, e.g. recovery and clean-up efforts and addressing issues on stakeholder engagement. Finally, the Fukushima Daiichi NPP accident produced additional information but also made explicit the benefit that the lessons learned from the previous accidents had in shaping the actions at the different phases of the accident. Some examples of KM initiatives and KMSs in the context of nuclear and radiological accidents that have been triggered before the Fukushima accident, and which are not necessarily limited to remediation, are described below. Efforts that are associated with Japan and that have been triggered before the accident, are introduced in the next sub-section.

In post-accident situations, new knowledge is produced daily. The significant volume and complexity of information generated as well as the possible security implications it may hold (e.g. in relation to potentially dispersed nuclear material) call for a systematic approach of record-keeping and its use as a ‘living tool’. This became apparent regarding TMI Unit 2 (TMI-2), where a vast amount of information was created and recorded through the collation of thousands of documents. Among others, the U.S. NRC’s NUREG/KM-0001 series collected around 4,000 documents evolving into volumes presenting overviews of the accident and technical details of recovery and clean-up activities (‘Three Mile Island Accident of 1979 Knowledge Management Digest’) [134]. Managing such collections is to expect revisions, which should be planned with due consideration of possible media obsolescence, resource limitations as well as the specific needs of the audience, anticipated to use the collections. One particular example of resource limitations is related to the archival of thousands of videotapes documenting TMI-2 clean-up and recovery efforts [135]. Another comprehensive record of the TMI-2 clean-up experience is given in EPRI-NP-6931 [136]. The publication focuses on decision-making, the influencing factors and options available, the final decisions and their consequences allowing for an enhanced exchange of knowledge and information with the public and the collection of valuable research and development information.

An example of collecting tacit knowledge in the context of radiological and nuclear accidents can be seen in the actions implemented after the Goiânia accident, in 1987 in Brazil, where qualitative and quantitative research was put in place conceived to gather knowledge from professionals who were involved in the activities related to emergency response and remediation of areas. The purpose was to understand how the lessons learned could contribute to the improvement of emergency response and remediation and how the collected information could be acquired and consolidated [137]. The questions were centred around three main points: i) Description of relevant aspects related to the accident; ii) Information on activities performed during and after the accident; iii) Main issues to be taken into consideration as useful lessons learned that could be applied in the response of a future accident.

An ensuing analysis of lessons learned [138] showed that:

- The coordination among different manufacturers providing diverse types of equipment for the detection of radiation was deficient, e.g. confusion was caused when using equipment with different displays and scales;
- Communication was lacking and inappropriate, and information disseminated was neither clearly nor sufficiently shared at all relevant levels:
    (a) The lack of knowledge on technical issues of journalists who reported what was deemed right and convenient, conveying, at times, incorrect information and generating panic among the population;

    (b) The inability of technical staff to properly liaise with the press. Technical personnel normally used to communicate with other peer professionals and were unable to recognize and address differences in needs and levels of communication with journalists who were not familiar with the technical topics at hand.

One of the main lessons learned after the accident in Goiânia was that the centralized management of radiation mapping through the setup of a local temporary laboratory would have been beneficial to assist in the coordinated calibration and measurements of the equipment, ensuring quicker answers and optimized tracking and monitoring. Centralized management would not only benefit dose measurements efforts but, more broadly, it would also warrant the most effective rollout of the emergency response. Following the accident, in Brazil, it was established that in the event of a nuclear or radiological accident, the military would take control and command of the operations with expert support and advice from the Brazilian Nuclear Energy Commission (CNEN) and other public services (e.g. Civil Defence and the Fire Brigades). An example of corrective actions triggered through the experience in Goiânia was the establishment of a public relation professional in those organizations to handle the response to a nuclear or radiological accident, ensuring targeted communication between technical professionals and the press. Furthermore, dedicated courses in radiation protection and emergency response have been made available. More information can be found in Ref. [138].

Regarding the Chernobyl accident, the IAEA incorporated lessons learned and recommendations concerning remediation in reports such as ‘Environmental Consequences of the Chernobyl Accident and their Remediation: Twenty Years of Experience’ [139].

By helping to put in practice specific actions in a defined strategy, handbooks developed at the national and international level have enabled the capture of lessons learned to aid the decision-making process, shape guidelines, and support and complement preparedness and policies. The project EURANOS (European approach to nuclear and radiological emergency management and rehabilitation strategies) under the European Commission's 6th Framework Programme, EURATOM Research and Training Programme on Nuclear Energy (2002–2006) has supported the development of three standalone generic handbooks for assisting the management of contaminated inhabited areas, food production systems, and drinking water in Europe following a radiological emergency (e.g. Ref. [140]. The handbooks contain state-of-the-art information on more than 100 management options. They are useful as a preparatory tool, under non-crisis conditions to involve stakeholders and to establish national, regional, and local plans. Furthermore, as part of the decision-aiding process, the handbooks can be used to develop a recovery strategy following an incident. They can be applied for training purposes and during emergency exercises. In Japan, they were used by the JAEA for identifying and improving remediation technologies. The overall structure of the handbooks is illustrated in Fig. 33. Supporting and background information is provided in several appendices.

FIG. 33. Structure and audience for the handbooks.

The UK Recovery Handbooks for Radiation Incidents [141−143] and corresponding tools [144] have been developed for assisting the management of contaminated food production systems, inhabited areas and drinking water supplies following a radiation incident. The three handbooks are user-friendly guidance documents, specifically designed to aid the decision-making process for developing and implementing a recovery strategy after a nuclear or radiological accident. The target audience includes national and local authorities, central government departments and agencies, radiation and health protection experts, emergency services, industry and others who may be involved in the recovery from a radiation incident. Included in the handbooks are decision-aiding frameworks for each environment with decision trees and look-up tables to be used as part of the decision-aiding process to develop a recovery strategy following an incident.

In terms of public and stakeholder engagement, several methods were utilized in the case of TMI-2, including those associated with the US NRC licensing processes as well as formalized panels and programmes. Regarding licensing, many of the evaluation processes associated with the licensee's clean-up and recovery plans required public meetings and solicitation of public comments.

One of the formalized programmes was the 'TMI Information and Examination Program', with members from GPU Nuclear, the Electric Power Research Institute (EPRI), the U.S. NRC, and the U.S. Department of Energy (DOE). The first letter of each organization formed the acronym 'GEND' for which the group became known. Numerous GEND reports were generated to document the findings of this collaborative effort. Other examples of formalized programmes included the 'Citizen Radiation Monitoring Program' [145] and the 'Advisory Panel for the Decontamination of TMI-2' [146].

The first programme aimed at informing citizens about radiation exposures and trained citizens to monitor, interpret, and publicize radiation levels to rebuild public confidence in the information supplied by government agencies. The Advisory Panel, constituted by members from local government and the scientific community, as well as residents in the vicinity of TMI, provided a vital connection to the local population, and, through regular meetings, direct lines of communication with the NRC Commissioners. Results were documented in several reports including an Electric Power Research Inst. (EPRI) report titled 'TMI-2 Post-accident Data Acquisition and Analysis Experience' (EPRI-NP-7156) [147], which provides a concise overview of data collection activities during the TMI-2 clean-up, 'The Citizen Radiation Monitoring Program for the TMI Area' [148] (GEND-008) and 'Lessons Learned from the Three Mile Island Unit 2 Advisory Panel' (NUREG/CR-6252) [146]. Periodic newsletters and annual reports were also issued to further capture the results of these programmes.

With respect to KMSs, JRodos [149], ARGOS [150], or the NARAC [151] system are some well-known decision support systems. These systems prepare decisive information for constructing a strategy with each new event, e.g. projections of the radiological situation, and analyses of the effectiveness of combined measures. Comprehensive decision support systems such as JRodos consider recommendations of national and international commissions. In general, computerized support for disaster management is a vital research topic that is reflected, for example, by the annually held Conference on Information Systems for Crisis Response and Management.

7.5. THE ACCIDENT AND KNOWLEDGE MANAGEMENT

This section highlights KM initiatives that are specifically related to the Fukushima Daiichi NPP accident – both in Japan as well as worldwide, or which are connected to Japan and the JAEA respectively. These initiatives are structured into areas of capturing lessons learned, promoting knowledge exchange, IT-supported solutions, and knowledge creation and structuring. In addition to providing an overview of the efforts made, the importance of KM and enhancement possibilities concerning KM initiatives are emphasized.

7.5.1. Lessons learned

Following the Fukushima Daiichi NPP accident, much effort was directed by the Japanese authorities towards the assimilation of experience accumulated from environmental remediation efforts put in place following previous accidents elsewhere. Experts on environmental remediation from JAEA reviewed various methods from national and international sources with regard to their applicability e.g. in respect of levels of contamination, the living conditions in Japan, and natural environment4.2.2. Many professionals were contacted and contributed their experience in support of remediation works there.

For identifying remediation measures in Japan, experimental and field-based demonstration projects were carried out in 2011 [7]. One of the reasons was the need to identify effective and applicable measures suitable for the site-specific conditions in Japan, as well as for the lack of experience in dealing with remediation of large areas and inhabited areas, and to train the workforce on the use of different equipment [7]. The results of the pilot projects were used for selecting and optimizing remediation technologies in the SDA and the ICSA being consolidated in guideline documents prepared mainly by the MOE in cooperation with relevant ministries. For instance, the Decontamination Guidelines initially provided by the MOE in 2011 comprised technical information on decontamination measures and were accordingly revised in 2013 [38] as more experience and knowledge have been gained, representing a reference source for defining and implementing decontamination projects. Furthermore, the MOE provided technical guidelines for designing and implementing TSSs [7] and published reports on the decontamination projects in 2015 and 2018 [38].

The knowledge provided by the demonstration projects and later by the large-scale decontamination works are valuable in terms of the planning and implementation of similar activities in case of future incidents. For example, all the measurements made during remediation were recorded including e.g. targeted surfaces, methods, waste, the equipment used and disposal methods [7]. Moreover, demonstration projects on recycling contaminated soil provide valuable knowledge to be compiled by the MOE in guideline documents.

KM plays a key role in ensuring that the knowledge base can be accessed easily by all stakeholders and that key parameters can be evaluated in an integrated manner. Therefore, besides documentation from demonstration projects, worker experience and hence tacit knowledge is essential for supporting implementation. This is a continuous process as further experience is acquired during the remediation works.

7.5.2. Promoting knowledge exchange

During the Fukushima Daiichi NPP accident, a lack of cooperation between the different European countries became apparent resulting in a diverging and non-harmonized response and confusion among the public [152]. To address these issues, NERIS — a European platform on preparedness for nuclear and emergency response and recovery, involving authorities, operators, technical support organizations, non-governmental organizations, and research institutes — was established. The objectives of NERIS are to share the knowledge throughout Europe, to achieve a better harmonization, and to support the development of tools and methods. The mission of the NERIS platform is “to establish a forum for dialogue and methodological development between all European organisations and associations taking part in decision making of protective actions in nuclear and radiological emergencies and recovery in Europe”, and is delivered through numerous workshops, training courses, and working groups.

Similar initiatives were put in place at the national level, In France, the nuclear safety authority (ASN), established a steering committee for the management of the post-accident phase of a nuclear or radiological emergency (CODIRPA), at the request of the Government and involving various stakeholders potentially affected by post-accident management, such as the public authorities, operators, associations, and experts [153]. The objectives are to improve protection for humans and the environment in case of a possible nuclear or radiological accident that might result in contamination of areas. The approach pursued by CODIRPA led to policy elements for post-accident management in the situation of a nuclear accident of medium scale, causing short-term releases, and are based on the international principles of radiation protection. Management objectives and actions for addressing such situations that are inherently extremely complex are also included.

7.5.3. Information Technology (IT)-supported solutions

Japan is a recognized world leader in the KM field as applied to radioactive waste management and has put in place a KMS in this area [154, 155] that could also be useful for remediation [156]. As an example, the general structure and main components of a KMS that have been developed for waste management and that can be adapted for remediation, are depicted in Fig. 34. The KMS includes all facets of tacit KM, focused quality management as well as anticipation of developments concerning technology and requirements in future. Tacit KM refers to, for instance, focused training and experience transfer schemes, which is frequently denoted as human resource management [141].

A support team (Knowledge Office) composed of people experienced in radioactive waste management and knowledge engineering being able to tailor established methodologies and tools effectively and efficiently to the requirements needed for developing the KMS has been regarded as crucial for success. Various types of knowledge are involved, and corresponding management functions are required in the context of waste management (see Table 10) that can be readily applied to remediation after an accident. In this regard, automation and/or computer support of KM functions is considered a key element in the implementation of this approach. The approach aims to provide an ‘intelligent assistant’ i.e. an electronic toolkit that enables project leaders and coordinators to master the large data flows to control and to focus only on the weighting and top-level synthesis and decision-making that cannot be automated [141].

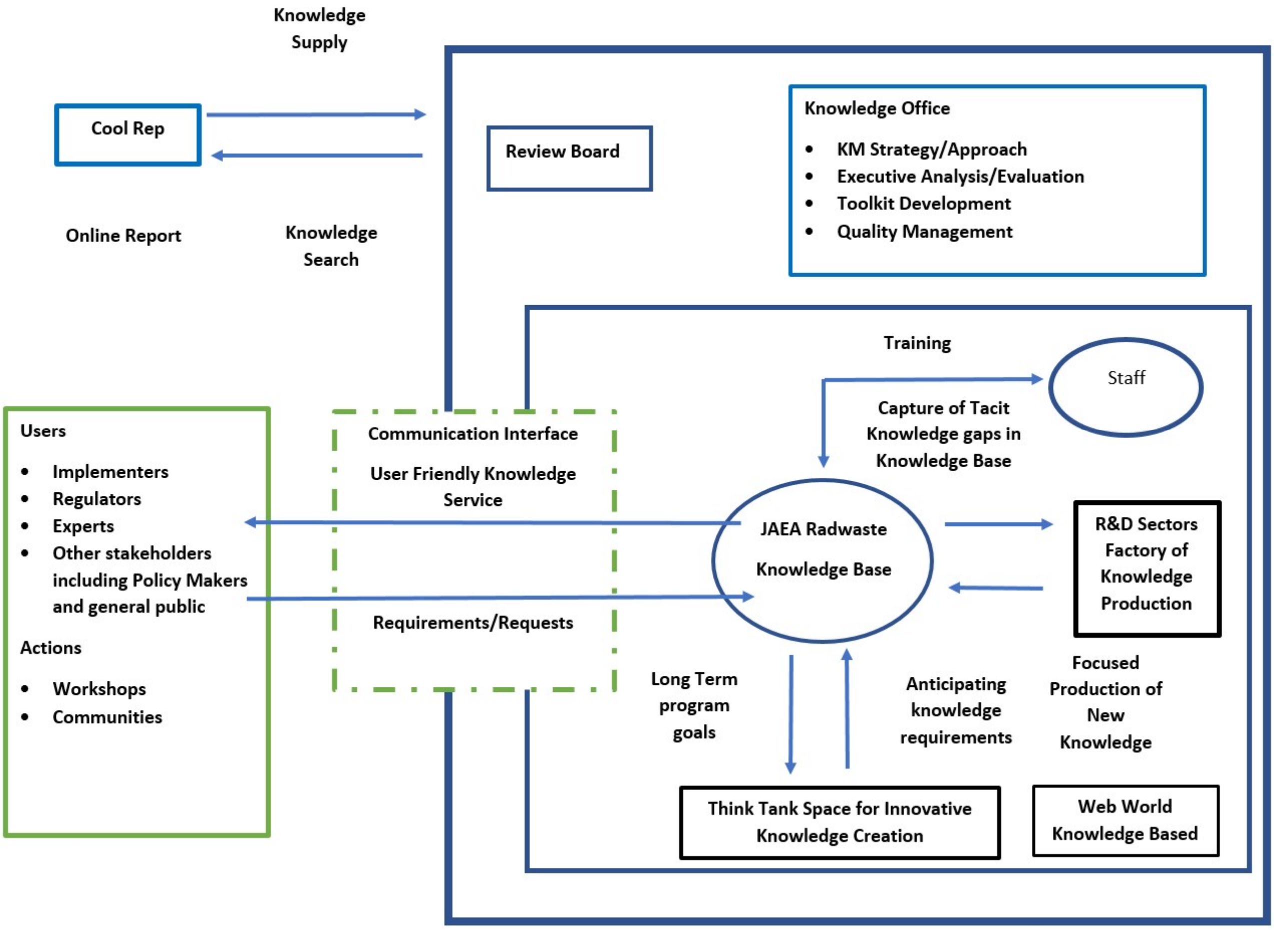

FIG. 34. Outline KMS concept structure and key elements (reproduced with permission)

TABLE 10. TYPICAL CONTENTS AND STRUCTURE OF A KMS THAT CAN BE APPLIED IN POST-ACCIDENT SITUATIONS, (reproduced from [141] with permission)

Form of knowledge	Management functions	Content	Needed developments potentially supported by IT
Data	Data management	– Raw data (internal) – Solicited data (external) – Processed data	– Robust archive – Internal and external data mining – Autonomic data processing; – Autonomic QA – Formal approaches for QA.
Documents	Document management	– Internal documents – Key external documents	– Robust archive. – Autonomic QA, cataloguing, cross-referencing.
Software	Software management	– Archive of all relevant codes and databases – Archive of manuals and handbooks – Archive of relevant input/output	–Robust archive – Autonomic change management – Formal approaches for QA.
Experience and methodology	Resource management	– Procedure manuals and guidebooks – Expert systems –Training materials	– Use of expert systems to capture and transfer tacit knowledge – Advanced training and experience transfer.
Synthesis	Knowledge integration	– Experienced synthesis team – Expert systems	– A formal description of key integration processes – Formal approach for QA
Guidance	Knowledge coordination	– Experienced coordination team	– Prediction of requirements (Think Tank); – Process for filling key gaps in knowledge.
Presentation	User and producer dialogue	– User-friendly interfaces (interactive – Allowing dialogue)	– High-end graphical methods for presenting complex information.

With the focus on nuclear emergencies and remediation, several decision supporting tools exist, estimating the type and amount of waste resulting from different remediation methods (Waste Estimation Support Tool - WEST) [60], supporting the planning of efficient and effective decontamination activities based on e.g. predicting future radiation dose rates (restoration support system for the environment - RESET) [61] and particularly estimating decontamination effects (calculation system for the estimation of decontamination effects (CDE) [62]. The experience accumulated in Japan, especially in terms of waste reduction, can further improve these tools aiming at assessing large-scale remediation projects more holistically.

Web technologies have enhanced decision support systems, in which analysis and computation are platform-independent, remote, and distributed, which facilitates information exchange and in which system maintenance is simplified and centralized [157].

In addition to accessing decision-supporting tools via a web browser, web technologies are suitable for enhancing communication and decision-making in distributed teams. As experience from previous events has shown, ensuring communication and collaboration among intervening parties, and creating a robust collective situation awareness are key factors in disaster management.

Regarding the Fukushima accident, numerous crowdsourced initiatives supported the mapping of radiation levels (such as Japan Geigermap) [158]. Using the Internet of Things platform Pachube (meanwhile Xively[10]), Geiger counters across the country were interlinked for aggregating and displaying online radiation readings from the public. Furthermore, the JAEA is collecting monitoring data including air dose rate and radionuclide concentrations in e.g. on the ground, surface and in food, as well as geographical information to be visualized and made available to the general public.

Pioneering work in terms of KM has resulted from the European project PREPARE[11] (Innovative integrated tools and platforms for radiological emergency preparedness and post-accident response in Europe) under the European Commission's 7th Framework Programme, EURATOM for Nuclear Research and Training Activities (work programme 2012, 2013-2016) [159]. The project aimed at closing gaps that have been identified in nuclear and radiological preparedness following the first evaluation of the Fukushima Daiichi NPP accident. Amongst various activities that included reviewing existing operational procedures in dealing with long-lasting releases, monitoring and safety of goods crossing national borders, improved source term estimation, and dispersion modelling including hydrological pathways for European water bodies, communication issues were also addressed, aiming at investigating the conditions and means for relevant, reliable, and trustworthy information to be made available to the public at the appropriate time and according to its needs. In particular, the 'Analytical Platform' was developed exploring the scientific and operational means to improve information collection, information exchange, and the evaluation of such types of disasters to be used by experts for analyses and information exchange and the public community to obtain information about an incident [160].

Experts can discuss their preliminary conclusions with the aim of getting a common picture transcending national borders. The Analytical Platform was evaluated regarding perceptions and expectations of potential users about the usefulness, trustworthiness, interaction with other users and governance offered by the system as well as the willingness and interest to join and contribute with expertise [161]. The interviewees were part of the NERIS community and partners of PREPARE (73 organizations) where 47% responded. The system was perceived as more useful for experts than the public and is used for centralizing information and enhancing collaboration and exchange between experts. In general, there was a great interest to participate. However, clear rules for sharing information were demanded. Political support from the organizations involved was needed to ensure the success of such a system.

The structure of the analytical platform containing several modules supporting the work of experts in analysing an ongoing event and communicating with the public is shown in Fig. 35. The platform can be accessed web-based and provides different tools for experts and the public

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[10] Xively is a system for deploying IoT applications on the cloud. It is offered as PaaS. Xively is basically a data collection, management, and distribution infrastructure. It also provides APIs to connect and develop IoT applications

[11] https://resy5.iket.kit.edu/PREPARE/

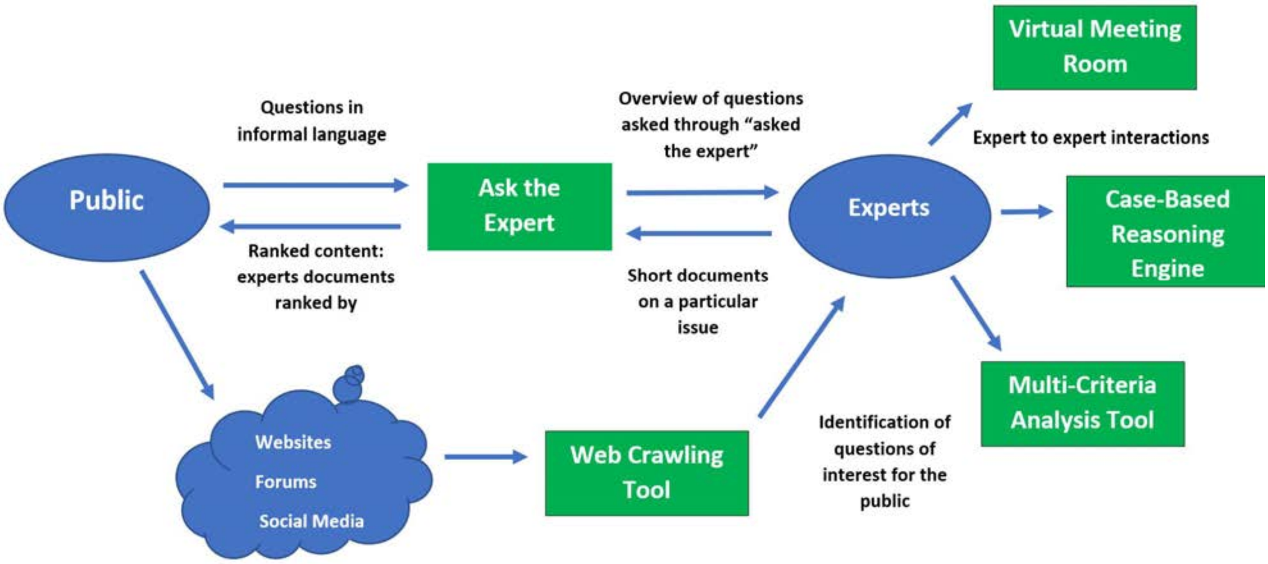

FIG. 35. Structure of the Analytical Platform [161]

Analysis tools such as the Case-Based Reasoning (CBR) engine and the multi-criteria analysis tool, as well as the virtual meeting room are available for experts. The CBR engine is built upon a knowledge database that contains information on historical events, their propagation with time and applied strategies as well as pre-defined scenarios [162, 163]. Originating from cognitive science, CBR utilizes specific knowledge of previously experienced problem situations to solve a new problem, where the main assumption is that similar problems have similar solutions. CBR is especially interesting for nuclear emergency management in terms of reusing already compiled knowledge of historical events as well as predefined scenarios of possible future events in a structured manner [164].

The follow-up European project, OPERRA-HARMONE[12] (Harmonising modelling strategies of European decision support systems for nuclear emergencies) under FP7-EURATOM-FISSION - EURATOM: Nuclear fission and radiation protection (2015−2017), extended the knowledge database focusing on strategies for inhabited areas and the food production system [165].

The multi-criteria analysis tool[13] (multi-criteria decision support (MCDA) tool) supports decision-making, considering multiple objectives (decision criteria) in a transparent manner and helps to rank a set of alternatives by integrating (contradictory) decision criteria of different scales according to given (personal) preferences [166]. This tool has been further developed in the follow-up European project CONFIDENCE[14] (Coping with uncertainties for improved modelling and decision making in nuclear emergencies) as part of the H2020 grant agreement 662287 – CONCERT (2017−2019), aimed at analysing uncertainties and improving the support for emergency management [167]. CONFIDENCE examined the influence of uncertainties on managing a nuclear accident comprising the assessment of data (weather, source term), simulation of the situation development (dispersion, food chain), analysis of possible countermeasure strategies (decision-support) as well as communication of situation development and strategies to the public (social science). The existing MCDA tool was developed further to handle uncertainties, for instance in criteria values or criteria

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[12] https://www.eu-neris.net/projects/operra/operra-harmone.html

[13] https://portal.iket.kit.edu/projects/MCDA/

[14] https://portal.iket.kit.edu/CONFIDENCE/index.php?action=confidence&title=objectives

weight values, where such uncertain values can be described probabilistically. The MCDA tool has been enhanced such that defining probabilistic input, performing ensemble evaluation, and presenting probabilistic results is possible [168].

Particularly regarding stakeholder involvement, tools that make decisions and uncertainties transparent are of utmost importance. MCDA in general is useful during remediation [169]. Analysing and modelling decision-making processes may also be interesting [170]. One may either store respective simulation results in a KMS or integrate the whole simulation software to be used for training purposes or in post-accidental situations.

In addition to providing analytical tools for experts, the public can get information about an incident provided by experts. Here, a web crawling tool automatically extracts questions of public interest from websites, forums, and social media [171]. Furthermore, the Analytical Platform may have different states differentiating an ongoing event from times of no crisis ('idle') (See Fig. 36*FIG. 36*). Depending on the state, diverse tools and information collections are accessible. For example, in case of an emergency, the public can receive information for improved situation awareness and guidance whereas experts can utilize tools for prognosis and decision support. This feature is especially interesting regarding centralized storage of knowledge. Times of no crisis can be used to compile knowledge, to look at issues and learn, and to prepare the retrieval of appropriate knowledge in case of an incident.

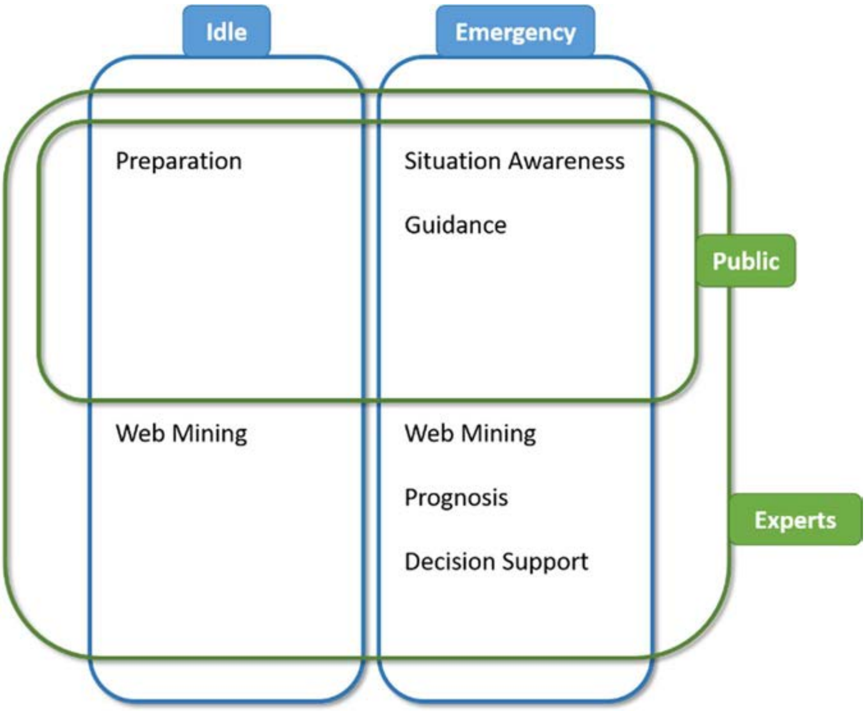

FIG. 36. States of the Analytical Platform with different users having specific privileges for accessing tools.

Aiming at preserving the knowledge base established through the IAEA Action Plan on Nuclear Safety and the publication of the IAEA Director General's Report on the Fukushima Daiichi Accident [7], along with five technical volumes, the IAEA has developed 'The Knowledge Management Portal on Observations and Lessons from the Fukushima Daiichi Accident'[15], to share observations and lessons in a structured and consistent manner. An online database allows a targeted search by topic such as safety assessment, emergency preparedness and response, radiological consequences, post-accident recovery, target audience, IAEA Safety Standards, and nuclear installation status being supported by pre-defined filter values.

7.5.4. Knowledge creation and structuring

Besides KM initiatives to capture, codify, store, share, and apply knowledge effectively, creating knowledge is essential here as well. That means, for example, to explicitly elaborate possible accident scenarios and appropriate remediation strategies in advance, to enhance records on historical accidents and to counter the issue on how to apply knowledge gained so far to an accident scenario [171, 172]. KMSs are useful to store results gained from exercises. In general, preparedness is central to counter the lack of knowledge and uncertainty. Similar accident scenarios, developed in advance, may help to better handle the many unknowns during an accident. These initiatives particularly need the knowledge of experts. At the stakeholder level, designing and building the knowledge base can contribute to learning from the past experience, highlighting challenges and opportunities for stakeholder engagement and identifying good and bad practices, thus helping to shape and improve future processes. In general, a proactive approach assuming the magnitude of the Fukushima Daiichi NPP accident is recommended on diverse levels of emergency management.

Some considerations that govern the need to structure any KMS to orientate the implementation of remedial actions in post-accident situations could include the following aspects as adapted from Ref. [173]:

- Capturing the order of implementation of measures: The idea here is that measures cannot be executed in an arbitrary order. For example, decontamination measures need to be implemented in a timely and logical order;
- Documenting short term and long term decisions and event developments: This supports the response phase as well as recovery phases;
- Capturing the effects of measures: This is of particular relevance when comparing different strategies;
- Capturing crucial factors influencing decisions on measures: These are important for identifying similar cases to the one being handled. Some of them are also important for reusing specific knowledge from similar cases for solving a current problem;
- Results of performance analysis: This is relevant again for the assessment of strategies.

7.5.5. Knowledge Management Systems supporting decision-making

Some elements that KMSs can provide to support decision making are provided below.

7.5.5.1. Drivers for establishing KM

In post-accident situations, new knowledge is produced on a continuous basis, e.g. in terms of lessons learned to be better prepared for future accidents. Furthermore, compiling knowledge gained so far, as well as further research, leads to updated recommendations and guidance material and consequently more knowledge. Hence, a systematic approach for record-keeping is of utmost

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[15] https://gnssn.iaea.org/FukushimaLessonsLearned/SitePages/default.aspx

importance, comprising means to integrate, combine, and process knowledge. The knowledge and information gained during the remediation in Fukushima, for example, are important for record-keeping in Japan as well as for sharing with the international community to be able to apply technologies and methods at other sites and in different contexts [117].

Crucial knowledge in this connection, may not stay in the experts' minds only or even hold by those who contributed to remediation works. Instead, this knowledge needs to be accessible as it will be an important source that will help guiding future remediation decisions in the unlikely case of another accident. Experience in Fukushima has shown that, along with training and education, outreach and stakeholder involvement is essential in environmental remediation projects [114] emphasizing the benefit of, for instance, communication based or communication supporting KM tools. Post-accident situations are of exceptional complexity in which, among others, knowledge from many sources and scientific disciplines need to be combined. The ability to make safe decisions and actions may be limited by knowledge gaps or knowledge loss emphasizing the need for suitable methods and supporting technology for managing competencies, information and records, work processes, techniques for analysis and verification, and for interpreting data [114]. However, the first step is to raise awareness and to value knowledge and KM as key resources.

7.5.5.2.The value of KM

KMSs provide means to capture and importantly, further disseminate knowledge that can support the implementation of actions for the remediation of affected areas in the event of similar events in the future, including information and codified knowledge as well as experiential knowledge. Knowledge held by the international community on routine remediation would not be always immediately applicable to post-accident situations. However, general KM approaches and methodologies would always be valid for the management of both explicit and tacit knowledge.

Although solutions that have been applied in a specific situation may not be completely applicable in a different context, there are always valuable lessons learned that help in framing the implementation of remedial actions in the case of a new accident by enabling access to information, as well as, importantly, experience and approaches from previous events. In this respect, elicitation of crucial knowledge from e.g. experts are of particular importance.

Hence, KMSs can aid decision-making processes by enabling accessibility and use of important information and approaches which have been gathered from experience in previous events, and which are important for decision-making. Suitable management options based on similar historical events or prepared scenarios could be identified to support remediation. Key parameters quantifying the pros and cons of the different options can be embedded in platforms supporting decision-making processes and the definition of strategies as well as the interaction among relevant stakeholders. A comprehensive KMS would combine and integrate functions for the contextualized handling of explicit and tacit knowledge throughout the organization being in the focus of a KM initiative [124]. Hence, most of the tools developed so far focus on specific KM processes. However, supporting tools can be fruitfully combined as could be exemplarily seen in the Analytical Platform.

7.6. SUMMARY OF KM INITIATIVES

For several years, KM has been highly appreciated in the nuclear technology field, being denoted 'Nuclear Knowledge Management' and promoted by, e.g. a specific programme launched by the

IAEA[16]. KM helps to develop and preserve expertise and experience throughout the nuclear technology life cycle, which might be very long and embedded in changing environments.

Past accidents underline the necessity to expand KM oriented thinking to disaster management and post-accident situations, respectively, to preserve and further develop valuable knowledge that is in danger of getting lost or not being readily available in the case of a new accident. The key role of KMSs in the scope of remediation of areas affected by radiological or nuclear accidents is to provide means for capturing and further disseminating relevant information (tacit and explicit knowledge) for supporting the implementation of management options in line with policy, strategies and plans that are laid out in guidance documents, as described above.

As emphasized in the report on decommissioning and remediation after a nuclear accident by the IAEA in 2013 [174], an internationally coordinated approach for KM is required to preserve knowledge, addressing issues on:

- Cataloguing information, knowledge, and lessons learned in a way that it can be easily accessed, also for learning, training and public information purposes;
- Extracting the value from the large body of knowledge, information, and data that already exists;
- Sharing knowledge and the importance of collaboration;
- Making knowledge available for long periods and especially for future generations;
- Additional costs that would result from losing valuable information and human expertise;
- Effectively distributing remediation knowledge and experience and providing assistance; especially beyond the countries that have applied and evaluated remediation actions.

The international expert meetings have emphasized that:

- Sourcing expertise and experience on technical support is challenging;
- It might be useful to establish a clearing house for recognized experts and prequalified firms;
- Workers need to be involved in planning and implementing a remediation strategy that might help to communicate issues with local communities and residents.

The experts have highlighted the importance of cultural differences that need to be addressed in programmes for sharing information and stated that commercial interest may hinder knowledge sharing. Therefore, international cooperation on the various aspects of remediation should continue and be strengthened particularly for supporting countries that might not be able to support the necessary technology. Regarding KMSs, the experts emphasized the need for visibility, linkage, and availability to the international community.

In conjunction with the Fukushima Daiichi NPP accident or related efforts made in Japan, several KM activities have been identified comprising triggered initiatives as well as tools that could be enhanced based on experience gained:

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[16] https://www.iaea.org/topics/nuclear-knowledge-management

- Monitoring data provided by the NRA[17] and JAEA[18] to be accessed online by the public (database for radioactive substance monitoring data);
- Assimilating experience that has been accumulated from remediation activities following previous accidents as well as approaching many experts to contribute and review diverse methods on the applicability concerning e.g. site-specific conditions;
- Guideline documents prepared by the MOE that especially consolidate experience made in the demonstration projects and the following decontamination work, to be further enriched by experience gathered in demonstration projects on recycling contaminated soil;
- Decision support tools for assessing and improving remediation operations, which could be enhanced e.g. with regard to waste reduction options based on experience made in Japan promoting a more holistic view on large-scale remediation projects;
- The JAEA KMS for radioactive waste management could be adopted or transferred to remediation providing diverse functionalities for supporting various KM processes.

In the international context, several KM related developments, partly previously initiated but further enhanced after the Fukushima accident, have been triggered, focusing on different KM processes:

- Lessons learned and corresponding documents as well as handbooks for identifying, developing, codifying, and capturing knowledge to be shared by the international community;
- Platforms and committees promoting knowledge exchange and the development of tools for emergency response and recovery with a special focus on improving decision-making capabilities;
- Developments concerning central and structured storage of experience and knowledge gained from previous events as well as fictitious scenarios and in collaboration with experts for supporting decision-making and constructing strategies;
- Specialized tools and methods that promote identifying and developing, structuring, evaluating, accessing, searching, visualizing as well as applying knowledge from the fields of artificial intelligence, operations research, and mathematical modelling.

Hence, with a focus on specifics of KM or with application in adjacent fields, diverse developments are recognized during recent years. However, accessing the large body of knowledge that has been accumulated in an easy, targeted, and contextualized way remains challenging. Furthermore, strengthening international collaboration is highly important to make current efforts visible, to link existing solutions, and to make the results usable for the broad community. Hence, discussing e.g. objectives and requirements on, for instance, a KMS applicable to different countries, in an international context, would be highly beneficial.

The Fukushima accident made explicit the benefit of the lessons learned from previous accidents as well as of compiled expert knowledge and experience for shaping actions at different stages of the accident. Knowledge is produced on a continuous basis and requires systematic approaches of

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[17] Monitoring Information of environmental radioactivity level NRA (nsr.go.jp)

[18] Measurement Results of Air Dose Rates Nationwide and in Fukushima Prefecture (Real-time Distribution), (FY 2011−FY 2018 Secretariat of the Nuclear Regulation Authority). Database for Radioactive Substance Monitoring Data (jaea.go.jp).

integration, combination, and processing for providing decision support and to be readily available when needed. The latter is especially crucial for any future remediation project.

Japan has long-standing experience in the field of KM and, for instance, has promoted the development of a comprehensive KMS in the field of waste management that, amongst others, appreciate advanced knowledge representation, smart search engines for enhanced access to the knowledge base, the importance of maintaining the knowledge base, appropriate interfaces for knowledge producers and users, and the development of tacit knowledge. Developments are especially driven by the needs of the knowledge producers and users. The approach and experience gained with this KMS development may be valuable to build upon and encourage similar activities in the field of remediation. Furthermore, due to its broad experience gained in conjunction with the Fukushima Daiichi NPP accident, Japan is one of the key knowledge holders in terms of remediation. The following general approach may help to shape future KM initiatives and develop a KMS concept:

- Defining goals: The scope of application needs to be clearly stated. For example, a KMS that incorporates diverse functionalities ranging from accessing lessons learned in a more general manner to concrete remediation strategies adapted to the problem context and which could be used as a ‘living tool’, would be highly beneficial. Japan together with collaborating international organizations could advise on, e.g. the type of knowledge needed for successfully implementing remediation operations, also regarding its adaptability to site-specific conditions.
- Sourcing and reviewing existing KM related tools and initiatives: Once the requirements on a KMS are defined, existing work could be used as a basis and be accordingly aligned. Aimed at being applicable in an international context, the diverse initiatives that have been triggered worldwide by the Fukushima Daiichi NPP accident constitute a valuable source for developing a comprehensive KMS. The experiences from Japan may guide the search for appropriate concepts and tools to be further enriched by international experience. In this context, Japan can clearly support and initiate key developments nationally and internationally.
- Integrating the identified core components, functionalities, and processes in a general framework: Transparency and communication particularly keep the design in line with the original goals. Furthermore, concepts on how to use the KMS for remediation need to be elaborated, including perspectives on e.g. maintenance and further knowledge acquisition and evaluation.

Japan is encouraged to elaborate a KMS concept based on experience gained during and following the Fukushima Daiichi NPP accident. As recognized during the accident, site-specific conditions including e.g., technical as well as societal aspects, challenge the selection of appropriate remediation actions. For providing decision support, these aspects particularly need to be respected. In general, to use knowledge in a meaningful way, the context in which knowledge is generated needs to be understood and stored accordingly.

8. RECOVERY AND REVITALIZATION

8.1. LIFT OF EVACUATION ORDERS

Immediately after the Fukushima Daiichi NPP accident, the Japanese government declared a state of emergency and set up the Evacuation Areas (No-Entry Zone) based on the Act on Special Measures concerning Nuclear Emergency Preparedness.

8.1.1. Areas designated immediately after the accident

The designation of the Evacuation-Prepared Areas in Case of Emergency was lifted on 30 September 2011, taking into account the safety assessment, the results of detailed monitoring as well as the restoration of public services and infrastructure.

The evacuation areas were re-categorized into three new areas as shown in Table 11 which presents the guidelines applied to each restricted area. Early return of residents was targeted by implementing required measures in areas with dose rates lower than 20 mSv/y whereas areas with levels above 50 mSv/y were designated a Difficult to Return Zone (DRZ) and the return of people was not expected at least for 5 years in this zone. In areas between 20–50 mSv/y named as the Restricted Zone for Habitation, temporary return of residents and passage of traffics are accepted.

TABLE 11. STRATEGIC PLAN IN EACH EVACUATION AREA AFTER THE REVIEW

	Annual Dose (mSv/y)	Target
Preparation zone for lifting evacuation order	< 20	Early return by achieving remediation, preparing infrastructure and creating jobs.
Restricted zone for habitation	20–50	Accepted area of temporary return of residents and traffic.
Difficult to return zone	>50	Generally considered as an off-limit area. No return at least with 5 years. Possibility of acquisition of land/real estate by government.

8.1.2. Requirements for lifting the evacuation orders

The NRA disseminated the basic approach to safety and security measures for return in November 2013 [175]. Subsequently, the NERHQ complied the measures to lift evacuation orders and promote the return of residents to their homes [176]. The requirements for lifting the evacuation orders were:

- The annual dose estimated by air dose should be 20 mSv or less;
- Infrastructure essential for daily life such as electricity, gas and water supply and sewage treatment, major transportation networks, and communications, as well as the life-related services such as medical care, nursing care, and postal services, should be restored (as much as possible) and the remediation work should be prioritized to restore children's living environments;
- Sufficient consultation with the Fukushima Prefecture, municipalities and residents should be put in place.

8.1.3. Progress in lifting evacuation orders

The remediation in the Preparation Areas for Lifting of Evacuation Orders and then, in the Habitation Restricted Areas has progressed with the consequent reduction of air dose rate. Because of this, evacuation orders were gradually lifted in the Preparation Areas for Lifting of Evacuation Orders and the Habitation Restricted Areas [177]. Lifting of evacuation orders was gradually implemented up to March 2020 except for most of the DRZ. The areas under evacuation orders were reduced from approximately 12% to 2.4% of the Fukushima Prefecture as of 10 March 2020 [178].

8.1.4. Towards the lift of evacuation orders in the DRZ

Access to the DRZ is restricted. On the other hand, a decrease in the air dose rates has been observed, and remediation and infrastructure reconstruction are simultaneously being undertaken. The construction projects are implemented with the aim of lifting evacuation orders within 5 years from the start of the projects. It is expected that dose rates of 20 mSv/y or less will be achieved. It is planned that the evacuation orders of the SRRB areas will be lifted during 2022 and 2023.

The preparations to accommodate the returnees will be accelerated after taking safety and security measures, followed by communication and consultation with the local community before the evacuation orders will be lifted.

8.1.4.1.Establishment of the Specified Reconstruction and Revitalization Bases (SRRB)

Each municipality included in the DRZ i.e., Futaba Town, Okuma Town, Namie Town, Tomioka Town, Iitate Village, and Katsurao Village, now have in place an SRRB in order to advance their recovery processes. The reconstruction and revitalization of industry, the improvement of public facilities and living environment as well as remediation and treatment of removed waste are being effectively and intensively accelerated, and thus, the living environment is smoothly and steadily being prepared in this area. The SRRB mainly consists of the Living Promotion Zone, the Communication Promotion Zone, the Logistic and Industrial Zone, and the Agricultural Regeneration Zone to help activities of returnees.

8.1.4.2.Safety and security measures for return

It is necessary to reduce the doses incurred by returnees and to address, as much as possible, their concerns regarding radiation after their return. The NRA, together with the Cabinet Office, the RA and the MOE, announced the basic policy on radiation protection for returnees with the following key points:

- The individual dose recorded by individual dosimeters rather than the doses estimated from air dose rate should be used to evaluate the exposure of returnees;
- The additional individual dose of 1 mSv/a or less is set up as a long-term goal in living circumstances after their return;
- Measures to further reduce doses and respond to health concerns will be implemented after lifting the evacuation orders.

8.1.4.3.Efforts to lift evacuation orders in the SRRB

In addition to the monitoring using individual dosimeters and establishment of a consultation system to communicate the results of the monitoring, the following key measures will be strengthened:

- Provision of information regarding estimated doses associated with specific behaviour patterns;
- Radiation mapping in the SRRB, dust monitoring and implementation of cleaning methods indoors to reduce internal exposure;
- Accurate and easy-to-understand risk communication and measures to address anxiety and health concerns: support from scientific and technical aspects to local governments, counsellors, etc. In this regard through the establishment and operation of the Radiation Risk Communication Counselor Support Center and other experts, consultation systems, life rebuilding support is established to address various concerns in daily life.

8.2. RADIATION DOSE REDUCTION IN THE LIVING ENVIRONMENT

The NRA announced that as a basic requirement of safety and security, protective measures should be taken in accordance with the dose levels to allow for the return of evacuees [179].

In the early stages after an accident, no option to measure individual dose using individual dosimeters was provided due to a lack of knowledge that the dose estimated from the air dose rate differs from the dose measured by an individual dosimeter. The doses, therefore, were estimated conservatively from the air dose rate.

8.2.1. Dose reduction in the Special Decontamination Area (SDA)

The air dose rate reduction is a key factor to promote the return of evacuees to their homes. The remediation widely implemented led to the reduction of radiation doses that were extensively measured in residential areas, farmlands, forests and roads after remediation in the SDA. More than 50% of dose reduction was achieved in residential and agricultural areas where residents spend most of their time, and less than 50% reduction was observed on roads and forests (as already discussed in Section 4 of this report). The lower reduction in dose rates in forests derive from the fact that decontamination was not fully implemented in these areas. Remediation activities were restricted to areas adjacent to living spaces and/or areas that local residents would frequently access. This strategy was taken considering a balance between the effectiveness of remediation measures to reduce doses to people and preventing collateral damage to forest ecosystems. A decrease in doses to the population was also due to weathering and natural attenuation. It is important to note that, driven by a sense of safety, residents in communities nearby forests have strongly requested remediation over the entire forests close to their living environment.

8.2.2. Ambient dose and individual dose

The reference level based on the air dose rate provided by the Japanese government was used to guide the municipalities and remediation contractors to plan and implement the full-scale environmental remediation. On the other hand, realistic approaches can help to more accurately estimate radiation doses related to specific lifestyles as a basis to plan necessary countermeasures for population groups potentially exposed to higher radiation levels.

Radiation doses estimates based on air dose rates are known to differ from the values obtained with the use of individual dosimeters. This is attributed to factors such as differences in residents' behaviour and the shielding effectiveness associated with different types of constructions. In order to reduce the exposure of returning residents and to mitigate anxiety, it is important for residents to understand their individual doses, especially in terms of the relationship between their lifestyle and exposure to radiation [180-182]. The dose incurred by returnees in the SDA, measured by individual dosimeters (except for the DRZ area), presented lower values when compared with doses estimated from air dose rate [183, 184].

Investigation on the influence of remediation in the reduction of air dose rates to residents of Soma town revealed limited effectiveness of such measures [183]. In areas with higher radiation levels, the effectiveness of remediation actions was more pronounced [185].

All these pieces of information created confusion amongst the population. Therefore, the NRA recommended that doses be measured by individual dosimeters, instead of being derived from air dose rates, to lead to a better understanding of the exposures of residents upon their return to their homes after being evacuated.

8.3. RECOVERY OF INFRASTRUCTURE FOR LIVING

Evacuation orders have been lifted except for the DRZ. The restoration of infrastructure has not advanced so quickly and in some cases, lack of proper maintenance caused by long-term evacuation was an issue.

8.3.1. Improving the living environment

Currently, residents who wish to return to their homes may hesitate to do so. Therefore, it is essential to restore the living environment so that normality can be restored as early as possible with the associated necessary attention being paid to address anxiety caused by radiation concerns.

The living environment and infrastructure have been improved and restored to accommodate evacuees in their original hometowns. The support for individuals and restoration of functions of public facilities were addressed. The following actions have been implemented in the SDA [92]:

- Housing: Reconstruction of public housing (4,767 completed out of 4,890 planned as of May 2020);
- Medical care: Medical institutions reopened e.g. Futaba Medical Center in April 2018;
- Reopening of nursing care facilities with operational support;
- Reopening of elementary and junior high schools (resumption of classes in 10 municipalities);
- Support for the establishment of publicly built and privately operated facilities for shopping of foodstuff and ordinary commodities (the Odaka Store in Minamisoma City opened in December 2018, the York Benimaru Haranomachi (supermarket) opened in Minamisoma City in Feb. 2020);
- The JR Joban Line is in full operation from 14 March 2020.

8.3.2. Fukushima Revitalization Acceleration Grant Project

The central government in cooperation with local administrations launched the acceleration project to restore and revitalize municipalities in the SDA. A series of measures were integrated with the project (including the restoration of existing water facilities or construction of new facilities; implementation of monitoring programmes in areas where evacuation orders were lifted; distribution of personal dosimeters in response to personal requests; allocation of counselling staff in municipalities; development of nursing care to address an increasing number of people requiring long-term attention in addition to the establishment of childcare centres and child-rearing support facilities to promote the return of a wide range of age groups; the establishment of a holistic approach for health management to mitigate and relieve the psychological stress caused by a long-time evacuation and to assist physically disadvantaged people; promotion of the use of local resources through the development of renewable energy supply facilities such as wood biomass and small hydropower; wood processing and distribution facilities) [186-188].

The allocated budget for this project was approximately Y31.3 trillion from 2011−2020, and further estimated at approximately Y1.6 trillion for the second reconstruction and revitalization period (2021−2025)[19].

8.4. MANAGEMENT AND RECONSTRUCTION

This session discusses the main aspects related to reconstruction vis-à-vis agricultural and aquatic ecosystems.

8.4.1. Agricultural field

An area equivalent to 17 298 ha among a total agricultural area of 20 809 ha distributed throughout 12 municipalities of the SDA have been affected by the Fukushima Daiichi NPP accident. After completion of full-scale remediation, the preparation for farming was initiated by means of the reconstruction of infrastructure required by farming such as irrigation. Agricultural-related specialists were dispatched to support these activities. The Fukushima Prefectural Agricultural Resuming Support Project provides an example of these initiatives. The objectives of the project included making a series of efforts to restore farmland, such as maintenance after remediation, demonstration of planting, measures against exposure to radioactive material, and creation of a new agriculture model. The step-by-step approach is described below:

- First stage:
  - (a) Maintenance and management of farmland after remediation;
  - (b) Emergency measures to prevent damage caused by birds and other animals.
- Second stage:
  - (a) Demonstration of planting for resumption of farming;
  - (b) Support for farmers to manage farmland originally owned by farmers who did not yet return after the evacuation;
  - (c) Prevention of contamination after harvesting;
  - (d) Support for resuming rice planting.
- Third stage:

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[19] This amount includes the reconstruction/recovery associated with the Fukushima Daiichi NPP accident and also the recovery associated with the damages caused by the Tsunami in the coastal region of Fukushima and other prefectures. Most part of the budget was allocated for reconstruction works within Fukushima Prefecture. For example, the projected cost in Fukushima is Y1.1 trillion out of a total cost of Y1.6 trillion during the period 2021−2025.

(a) Creation of a new agricultural model.

In addition, measures to decrease the uptake of caesium by crops have been implemented by means of the application of potassium to the soil throughout the project that is also aimed at restoring the trust in Fukushima Prefecture's agricultural products.

8.4.2. Forests

The Satoyama model project can be given as an example of recovery actions directed to forests. In those areas, residents live in close relation with the forests taking advantage of what the forests can provide. Therefore, safety needs to be addressed by lowering radiation doses. In order to do this, the model project called 'Satoyama Regeneration Model Project' was launched in collaboration with the RA, the MAFF and the MOE in March 2016 and the interim report published in 2020 [189]. The model project continued for three years intending to provide expertise for Satoyama forest restoration. Fourteen model areas were selected within 17 municipalities according to the community request. Basic measures included remediation of open spaces for the public, walking paths and bed-log laying yards for mushroom plantation. Litter was removed to reduce the radiation dose. Measures to prevent soil erosion and consequent loss of soil fertility were also implemented. Radiation doses decreased by more than the estimated value i.e. if only radioactive decay were considered. In flat areas, higher dose reductions were achieved as a consequence of more extensive litter removal. Broadleaf tree yards and bamboo tree yards were preserved by tree thinning, construction of working paths and log barriers to prevent soil erosion. Public use of forests was enhanced by means of different interventions. Moreover, forest maintenance contributed to the creation of new employment and sustained forestry industry. Maps of radiation dose were prepared, and individual doses were monitored by means of individual dosimeters.

If forest management such as thinning is neglected, degradation of the forest will accelerate, and multiple functions will be lost, such as watershed conservation or prevention of landslides, with consequent negative influence on the environment. The Fukushima Prefecture launched in 2013 the 'Fukushima Forest Regeneration Project' which tried to improve forests to maintain and enhance the forest functions and implement countermeasures to mitigate the influence of radiocaesium. The project was led by municipalities and other public entities and enforced forest management in the ICSA. Main measures included the following interventions:

- Surveying air dose rates;
- Measures to suppress the movement of soil by installing log terraces and fences;
- Management by thinning and cutting for regeneration;
- Construction of road network for forest maintenance.

The project involved 44 municipalities, and thinning was implemented in 4,888 ha and the forest maintenance road of 559 km was built by the end of March 2018.

8.4.3. Reservoirs and lakes

Waters in reservoirs and ponds contain relatively small activity concentrations of radiocaesium, mainly accumulated in bottom sediments. Caesium-137 was detected in the water column in 70 out of 288 water reservoirs in the SDA (with a maximum activity concentration of 86 Bq/L), and in 53 out of 2.287 outside the SDA (with a maximum activity concentration of 9 Bq/L). Caesium in water was mainly detected in those reservoirs with low water transparency (i.e., high turbidity) as these conditions are indicative of systems with high amounts of solids in suspension. This observation is in perfect agreement with what has been reported in Section 2. In 2014, caesium isotopes were detected in bottom sediments, in the range of 100 Bq/kg$_{dw}$ to 220 000 Bq/ kg$_{dw}$ in reservoirs outside the SDA. Reservoirs with radiocaesium above an activity concentration of 10 000 Bq/kg corresponded to 16.3 % of the total. Bottom sediments in reservoirs within the SDA showed activity concentrations varying from less than 100 Bq/kg$_{dw}$ up to 690 000 Bq/kg$_{dw}$ among which the number of reservoirs with activity concentrations of caesium isotopes over 100 000 Bq/kg corresponded to 10.8 % of the total

The MAFF published the fundamental technical guide for countermeasures on radioactive materials in reservoirs [189]. It was considered that waters in rivers and lakes have a radiation shielding effect. It was also assessed that the air dose rate in the surrounding areas of these waterbodies was hardly affected by radionuclides in rivers and lakes. Whenever these water bodies dry out, and consequently no shielding effect is to be expected, the living environment has the potential to be affected by the bottom sediments: in these cases, dredging of sediments might take place.

8.5. INITIATIVES TAKEN IN THE PRODUCTION PHASE AND FOR THE SAFETY AND SECURITY OF FOOD PRODUCTS

To ensure food safety, the Ministry of Health, Labour and Welfare (MHLW) announced four main actions which were adopted: i) establishment of activity concentrations limits for foodstuffs; ii) strengthening of food monitoring systems; iii) restrictions of distribution of contaminated food; and iv) increased transparency with all data and results coming from monitoring programmes being disseminated to the public [190].

8.5.1. Initiatives for safety and security of foodstuff

The radioceaesium level of every bag of rice was inspected by using a conveyer belt device equipped with a NaI scintillator. After confirming the radiocaesium level was below 100 Bq/kg, rice could be distributed with an inspection certificate on the bag.

The total number of inspected 30 kg brown rice bags reached 20.345 million in 2012. Bags with an activity concentration above 25 Bq/kg accounted for 0.0084%; those with an activity concentrations above 100 Bq/kg accounted for 0.0007%. After 2014, no bag with an activity concentration over 100 Bq/kg has been detected.

The Fukushima Prefecture checks the safety of locally produced vegetables and fruits before shipping. The levels of radioactivity in samples of these products is also measured at individual production areas with monitoring equipment such as NaI scintillation spectrometers. After ensuring the safety of the monitored items, the products are delivered and distributed.

Radiocaesium can be transferred to livestock products by animal ingestion of contaminated food. Therefore, proper animal food management is essential to avoid the undue accumulation of caesium in livestock. Reference values for feed were established to ensure that livestock products were kept under control. Table 12 shows the reference values for feeds to livestock.

TABLE 12. REFERENCE VALUES FOR FEEDS TO LIVESTOCK

Item	Reference values for feeds (Bq/kg)
Cattle	100
Pigs	80
Chickens	160
Cultured fish	40

All kinds of beef and other products are inspected, with the same process applied for vegetables and fruits before commercially being delivered.

In Fukushima Prefecture, inshore fishing and trawl-net fishing have been required to cease operation. However, the safety of stocks of some types of fish has been confirmed, based on more than 50 000 pieces of monitoring data. Since March 2017, the scope of trial fishing has been extended to all species of fish and shellfish except fish species under the shipment ban (7 species). All fish produced from trial fishing planned to be sold undergo inspection for radioactivity. The Fishery Cooperative Association set voluntary standards [50 Bq/kg], stricter than that of the national government for the national standard of “general food [100 Bq/kg]” for catches to be sold through trial fishing and conduct screening for radioactive substances. Full operation will resume in 2022.

8.5.2. Elimination of reputational damage

The economic damage to commercial sales was enormous due to the perception that agricultural and fishery products in Fukushima were contaminated. The shipping volume and price of each product decreased. Currently, both are gradually recovering but remain at a low level.

8.5.2.1.The transition of product delivery and export

Figure 37 shows the transition in the value (in JPY, unit 100 million) of the number of agricultural products including livestock produced in Fukushima from 2010–2017. Results are compared with 2010, a year before the accident. In terms of rice, the crop acreage and yield increased after 2012 but in 2014 and 2015, the nationwide rice price sharply dropped, and the rice output also significantly dropped in the prefecture.

Exports significantly decreased shortly after the accident; dropping by more than 90% in comparison to the levels before the accident. Many countries declared an embargo on Japanese products. A negative reputation affected the price of agricultural and fishery products. Housewives refrained from shopping due to the anxiety about the potential impacts of contaminated goods on their children. That happened not only in Fukushima but in the whole country. Even after several years, many Fukushima products present lower prices if compared with pre-accident values. The background assumption for this negative reputation is that the products are widely contaminated. Nevertheless, all products are inspected before delivery as described above. Despite all of that, the effort to enhance safety and confidence recovery with the prefecture and recognition of product quality has led to a steady increase in exports to Southeast Asia.

8.5.3. Countermeasures to eliminate negative reputation

It is essential to eliminate a negative reputation by building connections between producers, distribution hubs and consumers. These efforts can include sharing information and building social consensus, based on scientific facts. Governmental authorities, Japan Agricultural Cooperatives and Fishers Cooperatives are making enormous efforts to introduce Fukushima's products in the market, taking advantage of special occasions, such as antenna shops, fairs and exhibitions.

The RA announced the strategy to strengthen the removal of negative reputation and risk communication and has focused on stakeholder engagement as described in Section 6.

8.6. FUKUSHIMA REGENERATION PROJECT

Based on the Act on Special Measures for the Reconstruction and Revitalization of Fukushima, a couple of projects have been launched. In response to the local needs in the Fukushima Prefecture, the MOE took the measures not only for environmental regeneration but also for de-carbonization, material recycling and natural symbiosis towards the new stage of Fukushima reconstruction

The Fukushima Prefecture has a vision that the electricity in Fukushima will be supplied only from renewable energy by 2040, and the government provides the utmost support for the introduction of renewable energy and promotes cutting-edge research and demonstration projects to develop the systems with regard to renewable energy for producing, transporting, storing, and using hydrogen toward the creation of a hydrogen society.

The project includes the support of industrial creation to restore productivity, to support a decarbonization society, to restore livelihood, to pave a way towards 'Fukushima green' regeneration with the use of renewable resources and to support regional revitalization. The industrial creation programme supports the material recycling industry under the Fukushima Innovation Coast Framework. The demonstration and industrialization of cutting-edge recycling technology will be promoted in recycling spent solar panels and automated selection system technology using AI technology. The creation of a decarbonization society includes bus-sharing for life, a regional energy supply system with solar-sharing and biomass, smart agriculture and AI technology. The 'Fukushima green' regeneration includes support for making attractive national parks and environmentally friendly tourism with less generation of CO_2. For regional revitalization, risk communication and information dissemination will be strengthened by establishing two information centres and by rice production by volunteers. In addition, events to introduce Fukushima products were hosted by Fukushima Prefecture and related associations.

8.6.1. Fukushima Innovation Coast Framework

The government formulated the comprehensive framework for developing new industry infrastructure in the Hamadori area based on the Fukushima Innovation Coast Framework, which is addressed in the revised Act on the Special Measures for Fukushima in May 2017.[31]

The objective is that in the future the Hamadori district will be self-sustained by means of industrial development. Three pillars are expected to make the region a place where any challenge can be tackled, to convert the local enterprise into a leading player, and to develop human resources for sustaining the proposed framework. Under the pillars, some projects are prioritized: decommissioning of the NPP, robotics and drones, energy, environment, recycling, agriculture and fisheries, and medical and aerospace industries. Progress is as follows:

- Decommissioning:
  - (a) The international base for decommissioning R&D to accelerate the decommissioning of Fukushima Daiichi NPP has been established;
  - (b) The test facility for real-scaled demonstration has been built;
- Robotics and drones:
  - (a) The Fukushima robotics test field has been constructed;
  - (b) Cooperation of the World Robotic Summit has been proposed;
- Energy:
  - (a) New energy-related industry, such as renewable energy, has been created;
  - (b) A smart community that effectively utilizes renewable energy and hydrogen energy has been established;
- Agriculture, forestry and fisheries:
  - (a) Advanced agriculture, forestry and fisheries at the forefront over the country have been established;
  - (b) Development and practical implementation of advanced technology are being promoted in agriculture, forestry and fisheries;
- Medical-related industry:
  - (a) The industry with a medical-related support base has been developed in Nakadori-region;
- Aerospace industry:
  - (a) Consolidation of industries related to manufacturing aero engines, etc. has been expanded.

8.6.3. Creation of an international education and research base

While the Innovation Coast Framework initiatives are being promoted in Hamadori Region, human resources need to be fostered sustainably over the years because core educational and research institutions are not essentially prepared. The International Education and Research Base will be launched to provide talented human resources to the newly founded and reconstructed industry in this region and to create new industry through cross-disciplinary research and industry–academic–government collaboration.

The base consists of comprehensive institutions of national research and development agencies covering extensive research and industrial fields with the purpose of recovering from the nuclear disaster. The RA takes the lead in working to secure the budget and personal structure in cooperation with related ministries, such as the Ministry of Education, Culture, Sports, Science and Technology, the MAFF, the METI, and the MOE, and will reflect ideas of local governments, industries, and education and research institutions and examine ways to link and share roles between the International Education and Research Base and existing institutions. Regarding the fostering of human resources, Fukushima University and Tohoku University are intending to move part of their departments to the Hamadori area and establish a collaborative graduate school system. Seamless development of human resources is designed to involve local elementary, junior high and high school students. It is aimed to partially open by the middle of 2021–2025 and open fully by 2024.

Essential research fields include issues related to the creation of new industries on robotics, rural industries and energy, nuclear accident responses and environmental recovery. The research will closely reflect on practical industries. The holistic approach of the research is shown in Fig. 37.

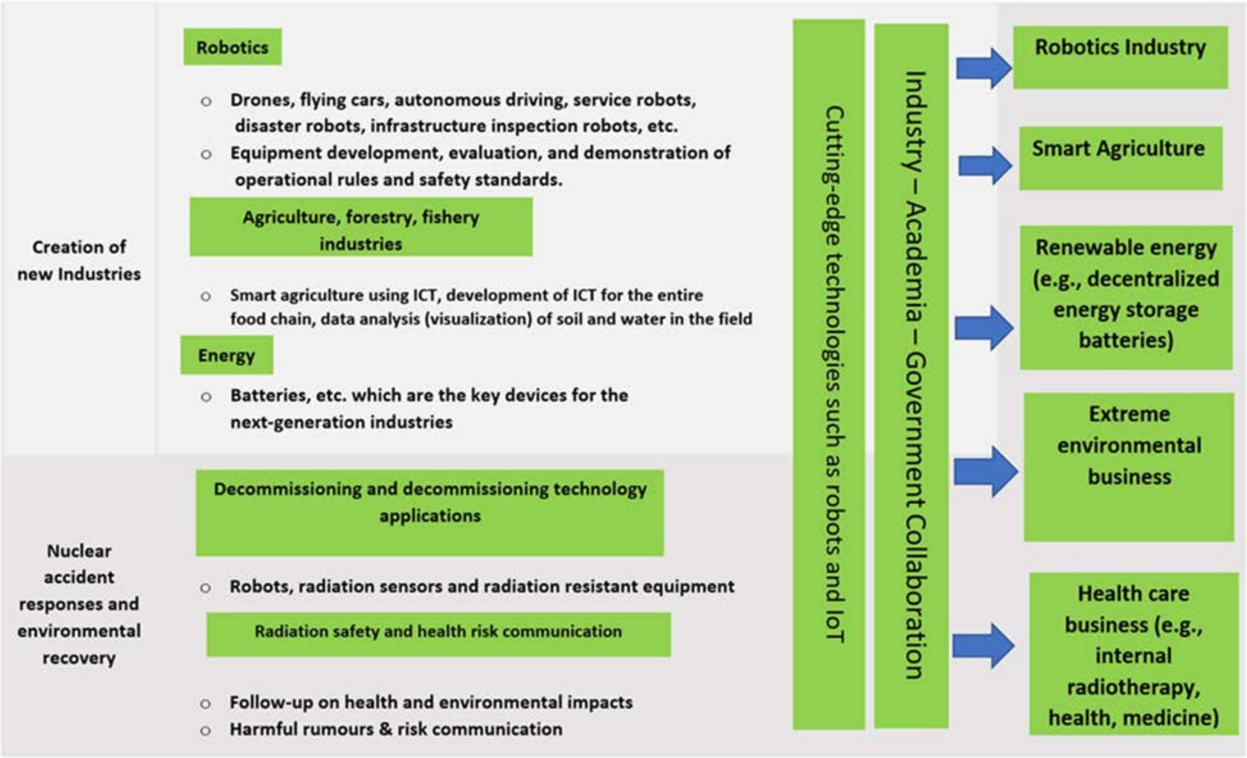

FIG. 37. The concept of the International and Research Base (reproduced with permission from MOE)

8.7. LESSONS LEARNED

In the aftermath of an accident, multifaceted support for physical and mental health is required. As a large number of people had to leave their homes following the Fukushima Daiichi NPP accident, accommodation for the evacuees became a top priority. Shortly after the evacuation, the central and local governments need to provide temporary houses. However, in the longer-term, more permanent housing needs to be provided and that requires governmental subsidies. For the returnees, infrastructure needs to be established and that includes medical care, shopping, education and transportation, in addition to the necessary infrastructure for the industry sector.

The longer the evacuation period becomes, the fewer people will return due to them having found new employment and schooling for children in the evacuation destinations [191]. The rate of returnees is higher among seniors especially those over 60 years of age than amongst the younger generations.

The mental health of evacuees is such a very critical issue. Counselling systems provide an opportunity for residents and evacuees to interact with specialists. Dealing with people's anxiety about radiation is the key. Most of the municipalities where residents were evacuated are similar in that the stability of life and health concerns are dominant issues. It is helpful that members of local communities keep in contact with each other and share information and support.

9. CONCLUSIONS

The Fukushima Daiichi NPP accident affected large areas in the northern part of the main island of Japan. A nuclear accident is an event that causes great psychological and social impacts, not only on the affected population at community, regional and national levels but also at an international level. This report did not address the response to the accident but instead dealt with the post-accident phase when remediation activities are considered. The report considered different aspects arising from the Missions organized by the IAEA in 2011 and 2013 and the series of four expert meetings when different aspects were discussed with representatives from the MOE so that exchange of experiences could take place and the Japanese counterpart could appreciate the perspectives imparted by the experts during these events.

Accidents are undesirable events. However, when they happen lessons need to be identified and shared with the broad international community to assist others in preventing future accidents, as well as helping others to deal with similar situations in the unlikely case they happen again.

This section summarizes the key messages from the IAEA–MOE meetings, in order to inform decision-makers, specialists, regulators and many other stakeholders, including members of the public about different aspects associated with the remediation of large areas affected by a nuclear accident.

9.1. REGULATORY FRAMEWORK

The existence of policies backed up by an appropriate regulatory framework constitutes a fundamental platform to enable the implementation of a holistic strategy for remediation and recovery of areas affected by a nuclear accident, especially when the efforts will encompass multiple organizations, institutions, and a diverse range of stakeholders. Establishing the institutional arrangements from scratch might be a time-consuming process and it will be quite challenging to have this task accomplished following a major accident. Therefore, it would be appropriate if discussions, not only within public organizations (e.g. national government, local governments) but also amongst local communities and other relevant stakeholders, occur prior to the unlikely occurrence of an accident. The need to develop national policy, strategies and means of the national dialogue for remediation of post-accident sites containing residual radioactivity was discussed in the IAEA led conference organized in Madrid 2016 [192]. It was also stressed that this needed to be done prior to a nuclear accident occurring. The Fukushima accident demonstrated that inaction in individual countries, due to fear of stigmatization by raising the possibility of accidents, needs to be avoided.

The Act on Special Measures [31] was a key piece in the overall remediation efforts. As described in Section 3.5.1, this Act established: the main purposes of the remediation programme; the distribution of roles and responsibilities among the involved institutions, namely the central government and prefectural and municipal governments; the role of stakeholders; the bases for monitoring, decontamination, and waste management; and the provision of financial resources.

The recommended adoption of reference levels between 1–20 mSv/a (see Section 3.4) represents a wide dose range that can cause a lot of misunderstanding. There is an understandable tendency to choose the lower value in this range because this could be considered to provide maximum protection of the public. Choosing any value above this lower level will require a lot of understanding and discussion and this is why efforts in this direction are better made in a situation in which the pressure and tensions caused by accident are not present. As a message for the international community, it is rather urgent that practical guidance in establishing reference levels in the scope of existing exposure situations, particularly after a nuclear accident, be provided.

9.2. REMEDIATION

The Fukushima Daiichi NPP accident resulted in the release of radioactive isotopes into the environment and because of that environmental remediation was implemented in different areas with the aim of protecting the general public against effects of ionizing radiation. The scale of contamination was unprecedented in Japan. Japan's efforts to remediate the affected areas have provided many valuable lessons as shown in the previous sections. The following topics represent conclusions arising from the remediation efforts carried out by the relevant Japanese authorities and can be taken as lessons to be considered in the unlikely occurrence of an event of similar magnitude that would trigger the need for comprehensive measures for the implementation of extensive remediation.

9.2.1. Terminology and its implications

As described in this report, remediation is defined as "any measures that may be carried out to reduce the radiation exposure due to existing contamination of land areas through actions applied to the contamination itself (the source) or to the exposure pathways to humans" [3]. In this regard, decontamination is one of the possible measures to be used to remediate a contaminated area because with the removal of the radionuclides from different media the exposure to radiation will (in principle) be reduced. But decontamination is not to be seen as the only or even the most cost-effective method of remediation and is not to be considered synonymous with remediation. The concept of decontamination may trigger an expectation that this involves the total removal of radionuclides. The IAEA Safety Glossary [3] advises against the use of terms such as 'clean-up' that may imply that the conditions that prevailed before the contamination can be achieved. Even the word 'contamination' may impart a meaning in laypeople that is totally different from its meaning in technical terms. In the IAEA Safety Glossary [3], contamination is defined as "Radioactive substances on surfaces, or within solids, liquids or gases (including the human body), where their presence is unintended or undesirable…". The fact that a surface is contaminated does not automatically imply an unacceptable risk: indeed, it may be the case that the associated risk is trivial and further measures to remove residual contamination may not be justified.

The remediation efforts that were implemented in Japan made it clear that dealing with such a post-accident situation goes way beyond technical and scientific issues. It is understood that affected communities, especially those people that had to be evacuated from their homes, will undergo different feelings from fear and frustration to anxiety and anger. But authorities may consider doing their best to, as much as possible, convey precise messages to avoid unnecessary misunderstandings and unjustified expectations.

9.2.2. Radiation protection experts

Radiation protection-related aspects underpin the decision-making on environmental remediation after a nuclear accident. Scientific information, as compiled by organizations such as the UNSCEAR, will play a key role in providing substance to the overall process. Therefore, the role of radiation protection experts will be of particular importance in this context. In addition to supporting the decision-making process, these experts will also play a role in disseminating information to a wide range of stakeholders. With that said, a divergence of opinion might occur among these experts, and even more between experts outside the field of radiation protection who might have their own views regarding issues such as the effects to be expected from exposure to low levels of radiation. It has been already suggested that "the lack of scientific proof of causality does not mean such causality does not exist" [193]. This is a source of confusion among the affected communities that might feel insecure regarding who to believe. It was reported, for example, that "some of the world's leading radiation experts scrutinized the same data and reached dramatically divergent conclusions" [194]. It is also to be mentioned that the dynamics of a nuclear accident will lead to changing scenarios with consequent changes in positions and decisions made by relevant authorities. It is commonplace to state that transparency and openness are key factors in the process, but reviewing and revising decisions, not disclosing information in real-time (i.e. because data needs to be validated before being made publicly available) and other issues will contribute to eroding the trust in the authorities.

Although scientific evidence is expected to inform the decision-making process, it is by no means its only driver; sometimes not even the main one. Many other things need to be considered and it is a mistake to assume that all that is needed is to ensure that scientific information is imparted by experts to members of the public.

In an attempt to minimise the potential for misinformation and consequent confusion amongst members of the public, governmental authorities may consider having in place mechanisms that provide proper coordination among experts (taking into account potential divergences that are to be expected in relation to individual professional judgment), to ensure that a reasonable level of coherence is achieved. As stated in Ref. [194] "the government developed substantial regulations, but the explanations for them often seemed confusing and contradictory".

9.2.3. Remediation approaches

The reduction of doses to members of the public results from a combination of different types of remedial actions and natural processes. In addition, due consideration is to be given to the appropriateness of implementing more aggressive remediation techniques, e.g. decontamination, instead of relying on monitored natural attenuation in combination with appropriate protective measures. This is a particular relevant decision to be made when resources are scarce or when the remedial actions have the potential to cause disruption in the ecosystem in different time frames. Overall, remediation is meant to produce more good than harm and that is reflected the core principle of justification. Clearly, however, this decision has also to consider many other societal and political aspects that might dictate the implementation of a specific approach. It has also been highlighted that it may be appropriate to have different approaches for urban land and farmland with greater delay for the remediation of the latter.

9.2.4. Remediation technologies

Many remediation methods have been applied. It is evident that there is no single technique or technology that can be universally applied in the remediation of different media and surfaces. Catalogues depicting technical details about different methods to be used in remediation efforts provide useful guidance; however, the effectiveness of different methods will depend on a wide variety of factors including expertise in how to apply them. The model projects were a very interesting and useful approach to set the basis for the application of different techniques. They were particularly useful in narrowing down the choice of the most effective remediation methods and to identify the technical and operational information tailored to the specific conditions. Making available a portfolio of remediation options for a member of the affected community to decide on the one(s) to be applied in their specific situation increases the engagement of stakeholders in the overall remediation process, eventually providing a sense of ownership regarding the applied solutions. But two problems need to be considered here. The first is related to the consequences of not appreciating the remediation results in the context of its life cycle e.g. not considering the generation of waste that will result from decontamination techniques and the long-term management that will need to be in place. The second one is to integrate individual decisions in a bigger picture to ensure that the summation of individual decisions does not have undesirable longer-term consequences.

9.2.5. Labour and equipment

Wide area environmental remediation involves an enormous amount of labour and equipment as observed in Japan's efforts. The authorities need to identify in advance how the remediation workers will be trained and equipped and how the equipment for remediation will be supplied. The trainers and training programmes have to be made readily available. The training programmes would then include, among other things, general guidance in fieldwork, radiation safety measures, training on specific remediation techniques, communication with different stakeholders, etc. Since it is not practical to have all the equipment to be used in a wide area remediation effort in stock, the authorities can identify which equipment can be used for remediation from other industries such as construction, farming, public works, etc. This identification includes how to train the equipment operators and how to decontaminate them after their use in remediation related activities.

9.2.6. Holistic considerations

Environmental remediation is composed of a series of interconnected activities. One activity (e.g. soil removal) will have an impact on the subsequent one (e.g. management of the generated waste). With that in mind, remediation efforts need to be considered in terms of the overall remediation time frame, and clear connections established between individual activities. It may be the case that one specific measure that might be seen at the beginning as a promising solution will be set aside if the overall impact in the remediation efforts is considered. Existing tools to support decision making need to be further developed to consider not only the direct aspects that drive the selection of a determined remediation approach but also those of a more subjective nature, i.e. reassurance and support of stakeholders. Conversely, whenever consultation with stakeholders is put in place with the aim of selecting a remediation approach for a given area or site, they need to be made aware of the consequences of such measures.

Of special concern are those situations in which the application of a specific remediation solution will impact the lives of more than one community.

9.2.7. Exercises

In many countries, exercises for responding to a nuclear or radiological emergency are conducted on a regular basis. It is also useful to conduct similar exercises for the case of remediation after such an emergency, or else extending the emergency response exercises to include remediation scenarios in such a way that it can be evaluated how the emergency response measures will impact the remediation to be implemented afterwards. Such exercises are, ideally, conducted with all levels of government and relevant agencies. As observed in Japan, the wide-area remediation may impact the community in various aspects including public health, economy, culture, etc. Therefore, the exercises will help to identify who needs to participate in and the roles and responsibilities of all organizations and institutions. In addition to the above, the exercises will help develop effective coordination among participants.

9.2.8. Effectiveness of decontamination techniques

One of the key elements in deciding about the adoption of a given method or technique for decontamination is how effective it is in removing contamination. This will, in principle, be determined by measuring the activity on a given surface or material. One needs to keep in mind, however, that the final goal of decontamination is to reduce the dose to individuals. In some circumstances, investing time and resources to decontaminate may not be justified because there is insufficient reduction in the individual doses to members of the community affected by the accident. The goal of removing all the contamination from a given area may be in the mind of those living there. However, as described previously, decontamination does not mean the living environment is returned to the existing conditions before the accident. In this regard, open dialogue will need to take place in order to increase the chances of finding some sort of consensus regarding the goal(s) of decontamination, taking into consideration the many aspects involved in the situation.

9.3. WASTE MANAGEMENT

The strategy for managing wastes generated by decontamination activities in the off-site areas of the Fukushima Daiichi NPP has reached significant intermediate targets e.g. operation, maintenance and restoration of TSSs, the establishment of the ISF, waste transportation operations from TSSs to the ISF.

The major lesson learned is that when planning remediation, radiological benefits to be achieved by decontamination of surfaces and areas need to be balanced against the safety, technological, economic and social problems associated with the management of the resulting wastes.

The strategy to manage decontamination wastes needs be thoroughly considered at the early stages of the planning of remedial works, as it can have a significant impact on the overall approach and the end-state of the remediated areas.

The nature of decontamination waste (which is mostly comprised of relatively low activity material consisting of contaminated soil, vegetation etc.) necessitates the application of specifically tailored waste treatment processes, storage and disposal technologies. In view of the large amount of waste, it is crucially important to consider segregation and treatment of decontamination waste for volume reduction to minimize interim and (especially) disposal volumes.

It is equally important to work out practical, safe and socially acceptable waste and soil recycling approaches in view of the large amount of material containing relatively low levels of contamination. In particular, contaminated soil recycling is of crucial importance in view of the need to minimize the volume of waste requiring final disposal.

Getting the understanding and consent from public and local authorities for various stages of decontamination waste management activities is not only a key pre-requisite but also a potentially important constraint on selecting the remedial strategy and its implementation.

Also important is to consider the adoption of clearance levels for remediation wastes, particularly for situations where restrictions of use will apply. Clearance is defined as “removal of regulatory control by the regulatory body from radioactive material or radioactive objects within notified or authorized facilities and activities.” [3] Therefore, clearance is a concept to be adopted in the scope of planned exposure situations, which is not the case for remediation after an accident that is characterized as an existing exposure situation. However, as the remediation of affected areas in Japan demonstrated, large amounts of materials containing low levels of contamination are generated in the process and their clearance and reuse could be considered in specific situations, i.e. in which the regulatory authorities (in consultation with a range of stakeholders) has defined clearance levels (in terms of activity concentration) for such materials to be used in pre-determined conditions.

The management of decontamination waste is ongoing in Japan and poses numerous technical, logistical and short-medium term issues that have to be fully and duly considered in any plan intended to address the remediation of large areas affected by a nuclear accident.

9.4. STAKEHOLDER ENGAGEMENT

The remediation works in Japan revealed a critical need to embed — from the start — stakeholder engagement in the development of policy, strategy and plans for post-accident remediation and recovery. This demonstrates the commitment of national and local administrations to transparent and open decision-making and makes visible the importance of stakeholder views in the whole process. However, achieving such an engagement in a constructive and cooperative way may be challenging.

Implementation of policy and strategy requires adequate resources, time and expertise to develop arrangements for a partnership that embraces national government, local authorities, agencies and organizations. These arrangements are essential for the development of stakeholder engagement plans and supporting information and educational resources - both efficiently and consistently. Involvement in the planning establishes good working relationships to deliver effective stakeholder engagement at a pace when a nuclear or radiological emergency occurs.

In Section 6, a series of efforts put in place by Japanese authorities, most prominently the MOE, are presented. These efforts are remarkable, yet room for improvement will always exist. It is normal to focus attention on what did not go well instead of acknowledging the efforts to get things right. In particular, in the case of an accident, it is possible to start to lose the trust of affected persons from the very beginning. Therefore, it requires great efforts to communicate, engage and make decisions in a participatory capacity. As stated in Ref. [195] “public opinion on nuclear power in Japan has changed dramatically since the Fukushima accident. It is suggested that this was caused by lack of trust, especially of the government but also of the nuclear industry and nuclear experts”. As a result, the borders between the actions targeting the remediation of affected areas and the overall circumstances related to the accident are diffuse, and perception of one thing can compromise people’s attitude regarding the other. A recurrent message is that communication and engagement cannot take place on the occasion of an accident, it has to be a continuous process. The challenge is that this may prove to be quite unrealistic and will compete (or at least go in parallel) with governmental efforts in other areas.

9.4.1. Facilitating effective stakeholder engagement

The authorities managing post-accident remediation programmes also need to consider how to meet the diverse needs of stakeholders, so they understand, trust and make effective use of information provided. The Fukushima Daiichi NPP accident has highlighted the diversity of stakeholders involved in remediation, waste management and revitalization. Stakeholders will have different information needs and their views and perceptions will be influenced by location, their perspective on uncertainty and their tolerance of risk. They may live in the area affected by the accident, they may be impacted by remediation, or may live further away. They may be influenced by hearsay and misinformation, which needs to be recognized and managed. Scientists, decision-makers, and people affected by a radiological emergency will also have different perspectives on uncertainty which may cause problems with communication. This highlights the importance of understanding the information people need to have so that they can make informed decisions. Presenting information in formats that are both accessible and inclusive, whilst building trust with stakeholders, is a key challenge for national and local government and the radiation protection experts supporting them.

Overall, the experience accumulated during the preparation of this report confirms what is discussed in Section 2, namely the need to implement a shift in the policy and decision-making process from a top-down approach to a bottom-up approach in order to promote public engagement. This would contribute to improving legitimacy and trust in government institutions.

9.4.2. Understanding risk

In addition to trust, another recurring issue when dealing with stakeholder communication and engagement is the communication of risk. It is reasonably understood by members of the public that exposure to ionizing radiation has the potential to cause harmful effects to human beings. The differences between acute and chronic health effects might not be so clear. As a result, there may be a discrepancy between perceived and actual health risks, and this has a profound impact on the way environmental remediation is implemented. It is important to note that perception of risk associated with exposures to ionizing radiation is an issue of crucial relevance to environmental remediation. It has been reported that different stakeholders are becoming increasingly concerned about radiation exposures from diagnostic or therapeutic medical procedures [196]. As such, patient perception of radiation exposure strongly influences their acceptance of diagnostic examinations or therapies involving radiation.

When the environment is affected by an event that causes contamination such as a nuclear accident, it is quite logical that the first thing that comes to the minds of the affected population is to remove the contamination and return the environment back to pre-accident conditions. They might understand that this will not be possible, and that some residual contamination will be left. When presented with reference levels for existing exposure situations (in the range of 1–20 mSv/a) it is also natural that the lower end of that range is taken as an endpoint as it will be seen as representing a lower risk. However, this risk needs to be balanced against other factors, and radiological aspects cannot be seen as the sole driving factor in the decision-making process. The consideration of other factors is inherent in the radiation protection principles of justifications and optimization; however, this is not always straightforward in terms of their practical application. During the IAEA conference on Decommissioning and Environmental Remediation held in Madrid 2016 [192], participants recommended further development of internationally recognized guidance on the selection and implementation of reference levels for existing exposure situations i.e. in remediation programmes.

The conclusion is that efforts need to be put in place to ensure that stakeholders understand the concept of risk, the full remediation time frame, and the balance between reducing exposure and (for example) increasing waste volumes, in order to allow for a better understanding of the implications of each decision being made and ensuring that decisions are not assessed in isolation. Achieving these goals requires a proactive, rather than reactive, approach to engagement.

9.5. DECISION-MAKING SUPPORTING TOOLS

Decision-making after a nuclear or radiological accident is extremely complex. The response to the Fukushima Daiichi NPP accident made clear the benefits of knowledge gained from previous accidents in shaping the actions at the different accident phases. It is therefore of the utmost importance to share lessons learned and use good remediation practices and, to ensure the competence of the personnel involved in remediation, and to transfer knowledge to future generations. KM provides a means to preserve holistically and systematically, share, apply, and develop crucial knowledge for remediation. Therefore, establishing KM systems in the field of remediation needs to be further promoted to ensure, amongst other things, that knowledge gained will be readily available to be applied in the unlikely case that a future accident occurs. In this connection, an internationally coordinated approach is needed, covering KM objectives, core processes, and implementation steps.

For establishing new KM programmes or improving existing initiatives over the long term, diverse challenges need to be addressed:

- Knowledge transfer and sharing are necessary across organizations, regions, and states, which underlines the importance of international collaboration and approaches. In terms of developing a KM system, questions on the scope (nationwide or across national borders) and system requirements (focus on different aspects of KM, and the need for an integrated approach) need to be comprehensively discussed.
- Regarding transnational implementation and platforms, it is recognized that political support from governments, authorities and expert institutions is critical to the success and long-term commitment and that clear rules are required for the use of shared information.
- Competencies and knowledge need to be transferred between generations making maintenance of knowledge and supporting systems, respectively, important issues that need to be addressed.
- Decision-making tools can be helpful in assisting the overall decision-making process, especially if they are linked with KM systems that can provide the necessary input to run such tools. This topic is crucial considering the diverse stakeholders involved in decision-making processes. Tools such as multi-criteria decision analysis may be highly beneficial for remediation and the incorporation of Artificial Intelligence mechanisms to aid the decision-making process merits further consideration and could indeed represent an important development in this area.

9.6. RECOVERY AND REVITALIZATION

In addition to environmental remediation, restoration of the living environment is a critical issue in the early stage of recovery after an accident. Arrangement for housing, restoration of infrastructure such as electricity, water, food supply and the logistics system need to be provided under the strong support of central and local government. Mental health support from a multi-faceted approach also needs to be provided, including access to counselling and community revitalization.

If the period of evacuation is long, fewer evacuees may wish to return to their original homes, because evacuees eventually settle by finding new schooling and new jobs in the area to which they have moved. The issues change over time from anxiety related to radiation exposure to worries about new living arrangements.

In the particular case of Japan, the regeneration of rural areas where agriculture is one of the main economic activities is essential to promote the return of evacuees. Regeneration projects need to be launched under the support of the government and related authorities.

The creation of new rural industries would contribute to the rebuilding of society in affected areas and even attract new settlers. Forests and surrounding areas were used for the cultivation of mushrooms, playground for children, parks, recreation, etc. The SATOYAMA project implemented is an informative programme for the restoration of forests [189].

Children of evacuees or students who were relocated may have suffered from groundless negative rumours. Truth based on scientific evidence needs to be disseminated by various means.

In the early stages after the accident, some foodstuffs were affected by radioactive contamination; however, even in later stages, when the contamination levels were no longer of concern in terms of the radiological risk, production and sales were markedly decreased due to the spreading of negative rumours. The programme of inspection of radioactivity in foodstuffs proved to be a powerful mechanism to demonstrate the safety of these products and the results obtained have to be disseminated broadly within and outside the country. The government and related entities need to provide support with multiphase approaches to overcome any negative effects caused by rumours.

A holistic approach to regenerate and reconstruct affected areas from which residents have been evacuated, and in which infrastructure was damaged, is essential to create a new community, ideally with the engagement and with the cooperation of residents. The central and local government need to provide support by formulating a regulatory framework as well as providing funding for these initiatives.

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ABBREVIATIONS

AESJ	Atomic Energy Society of Japan
DF	Decontamination Factor
DRZ	Difficult-to-Return Zone
EURANOS	European Approach to Nuclear and Radiological Emergency Management and Rehabilitation Strategies
EURATOM	European Atomic Energy Community
GPS	Global Positioning System
HEPA	High-Efficiency Particulate
ICRP	International Commission on Radiological Protection
ICSA	Intensive Contamination Survey Areas
ISF	Interim Storage Facilities
ISFIC	Interim Storage Facilities Information Center
JAEA	Japan Atomic Energy Agency
JESCO	Japan Environmental Safety Corporation
KM	Knowledge Management
MAFF	Ministry of Agriculture, Forestry, and Fisheries
METI	Ministry of Economy, Trade and Industry
MHLW	Ministry of Health, Labour and Welfare
MOE	Ministry of the Environment
NERHQ	Nuclear Emergency Response Headquarters
NPP	Nuclear Power Plant
NRA	Nuclear Regulation Authority
NRC	Nuclear Regulatory Commission
PES	Provisional Estimation Standards
RA	Reconstruction Agency
SDA	Special Decontamination Areas
SRRB	Specified Reconstruction and Revitalization Bases
TEPCO	Tokyo Electric Power Company
TIF	Temporary Incineration Facility
TMI	Three Mile Island
TSS	Temporary Storage Site
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation

CONTRIBUTORS TO DRAFTING AND REVIEW

Attwood, C.	Environment Agency, UK
Bugai, D.	Institute of Geological Sciences, Ukraine
Inoue, T.	CRIEPI, Japan
Kuroda, H.	Ministry of Environment, Japan
Lee, S.D.	EPA's Office of Research and Development, USA
Moehrle, S.	Karlsruhe Institute of Technology, Germany
Monken-Fernandes, H	International Atomic Energy Agency
Mori, Y.	International Atomic Energy Agency
Nakano, T.	Ministry of Environment, Japan

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