Remediation of Contamination from Radioactive Material by the Fukushima Dai-ichi Nuclear Power Plant Accident

"Nuclear Safety" Investigation Committee Clean-up Subcommittee
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The clean-up subcommittee under "Nuclear Safety" Investigation Committee, which aims to propose environmental remediation methods from radioactive material contamination in the areas outside the power plant, has proposed an early establishment of the radiation monitoring and the environmental remediation centers and development of the environmental remediation strategy and environmental remediation technology program with cooperation from the local residents. Moreover, this study introduces the knowledge gained from the Chernobyl Accident, which experienced similar contamination of the surrounding area, from the perspective of the environmental remediation. On the contrary, the environmental remediation faced problems, including the inability of the legal system to treat the contaminated debris and other wastes as industrial waste and the absence of the safety standard in environmental radiation for lifting the evacuation order.

I. Activities and Proposals of Clean-up Subcommittee

1. Activities of Clean-up Subcommittee

The clean-up subcommittee of "Nuclear Safety" investigation committee was established for analyzing the decontamination and environmental remediation of the areas in and around the Fukushima Daiichi Nuclear Power Plant (hereafter power plant) contaminated by the radioactive materials that were released after this accident, examining the problems, and suggesting proposals toward their solutions.

Regarding the power plant premises, the medium/long-term perspective, which includes 1) identification of the problems related to the removal of melted fuel and its processing/disposal and 2) analysis of the contaminated water processing and types and quantity of contaminated waste as well as the identification of problems related to processing/disposal of radioactive waste, is required, and the subcommittee will propose an environmental remediation plan when required.

Regarding the area outside the premises of the power plant, we plan to conduct identification and analysis of the contamination, identify the problems related to the removal

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and processing of radionuclides from a vast and diverse amount of contaminated materials in the environment, and explore the comprehensive environmental remediation strategy. Through these, we will suggest proposals about the remediation activities and propose technical programs for feasible remediation processes involving the entire stakeholders. Moreover, we already provided four proposals, as mentioned below, on the environmental remediation policies that will be required in future, including the necessity of the environmental radiation monitoring center and the environmental remediation center in the contaminated area.

2. Proposal 1: Early Establishment of "Environmental Radiation Monitoring Center" and "Environmental Remediation Center"

(1) Establishment of "Environmental Radiation Monitoring Center"

Since the measurement data for the environmental radiation that is conducted individually by each organization has different settings in measurement condition or unit depending on the purpose of each measurement, it is difficult for the general public to understand these data. Therefore, we suggest that establishing an "environmental radiation monitoring center," where these data are consolidated and comparison of measurement points or changes over time are comprehensively analyzed, will be effective. Moreover, monitoring requires cooperation with the relevant local municipalities to obtain and collect the detailed data, and in turn, it is important to promptly explain the collected data and the analysis results to the residents through the municipalities. In addition, considering the severe anxiety among the people in areas around the disaster zone about the effect of radiation on human body or the future prospect regarding the radioactive materials released into the environment, establishing a regular explanation system for the local residents by the specialists of radiation protection in parallel with the establishment of this radiation monitoring center is urgently needed.

(2) Establishment of "Environmental Remediation Center"

Establishment of an "environmental remediation center," which can engage with the environmental remediation of both the areas in and around the premises the power plant, is proposed. Currently, the electric companies and the Japanese government are focusing on the stabilization of the situation after the accident inside the power plant premises. This subcommittee plans to evaluate these plans and the implementation policies and will be offering suggestions when required. In addition, we will examine and offer proposals on the technical policies of the melted fuel removal and the processing/disposal of the vast amount of contaminated water, which are short and long-term problems.

The preparation of a unified plan for the future and its implementation are urgently required in the environmental remediation of the area outside the power plant. In response to this situation, the environmental remediation center must first prepare a comprehensive strategy [1] for the environmental remediation, present applicable technologies, and specify the implementation plan and policies. Moreover, this strategy must include a remediation plan for the removal of soil, water, and dust that contain radioactive material using existing technologies. That is because the time of evacuation is getting prolonged due to the release of radioactive material in the area outside the power plant premises, and it is causing severe anxiety to the local residents for their future. Additionally, a rational and effective radioactive material

[1] Comprehensive strategy refers to a total environmental remediation strategy for the large areas in and outside of the nuclear power plant based on the importance of the lives of the local residents, proposing applicable technologies and their implementation method that includes the processing and disposal method of the secondary waste as well as preparing an effective decontamination plan.

removal technology must be developed because there is no guarantee that the existing technologies will be enough for the complete removal of the radioactive materials.

On the contrary, it is important to quantitatively understand its effect in advance while conducting the actual radioactive materials removal work. Therefore, establishing a practical test site in the disaster zone for examining the effectiveness of removal technologies used in the remediation as well as for verifying the problems in the actual work is an important role of the environmental remediation center.

As mentioned above, we propose to establish an "environmental remediation center" in the disaster zone for planning strategies for environmental remediation, presentation of technologies, and comprehensive implementation of practical tests and technology development. The clean-up subcommittee aims to actively collaborate with its establishment and operation.

3. Proposal 2: Preparation of Environmental Remediation Strategy toward the Removal of Radioactive Materials

(1) Preparation of Environmental Remediation Plan Based on Radiation Measurement

Maps of air dose rate or radioactive material concentration in soil are necessary for preparing an environmental remediation plan. Moreover, the environmental remediation plan must be based on the usage of the land and facilities considered in the plan as well as the practically achievable removable effect of radioactive materials. On the other hand, it is assumed that the environmental remediation will require a long period of time. Therefore, it is necessary to set stepwise goals when required and conduct remediation with steady and continuous effort.

(2) Priority Determination in Environmental Remediation Based on Objective Indicators

While there are facilities being used by many people in the areas that are targets of environmental remediation, such as hospitals and schools, among the other public buildings, there are places where hardly which are not visited regularly such as mountains and forests. Further, for the case of farmlands in mountain areas, environmental remediation itself may not be sufficient as there is a possibility of the long-term effects from mountains and forests on the farmlands. Therefore, it is important to consider the impact of the radiation on the people living and working in the area, and the implementation of environmental remediation requires setting priorities based on a comprehensive examination. We consider that determining the actual priority of environmental remediation based on objective indicators of the concentration of radioactive materials in the target facility and location as well as the environmental factors, i.e., mode of usage, frequency of usage, among others, is fair and effective.

(3) Adaptability Evaluation of Rational Environmental Remediation Technology

It is predicted that, as a result of environmental remediation work, a large quantity of waste containing concentrated radioactive materials will be generated. Moreover, secondary wastes will also be generated as a result of various works. Therefore, it is important to examine the processing and disposal policies while grasping their quantity, types, and the concentration of radioactive materials properly. Meanwhile, quantitative evaluation of the exposure risk of the environmental remediation workers and the examination of protection plans are indispensable factors during the preparation of environmental remediation strategies.

4. Proposal 3: Early Presentation of Environmental Remediation Technology Program

(1) Early Presentation of its Final Appearance and Stepwise Goals

It is necessary to clearly indicate the achievable final target figures of the reduction of the exposure dose rate and radioactive material concentration through environmental remediation together with the time scale in advance. Moreover, if achieving the final target requires a long time, presenting the stepwise goals (exposure dose, environmental remediation area, among others) for each time period will be an important indicator for the local residents.

(2) Identification of Definitely Achievable Environmental Remediation Effect

Presentation of existing candidate technologies applicable to the target areas and land categories together with a quantifiable efficiency of environmental remediation is required for the early start of remediation work. While selecting the applicable technologies, the types and characteristics of wastes must be taken into consideration, in addition to their expected environmental remediation effects. Meanwhile, while the development of a new technology is necessary, it is required to identify the problems and start developing the technology promptly. Moreover, it is desirable that relevant Japanese organizations cooperate with each other and bring together their knowledge to implement and develop technologies for environmental remediation. (Currently, each organization works in isolation and there is no unified effort.) The clean-up subcommittee of the Atomic Energy Society of Japan wishes to evaluate the expected environmental remediation effects and the applicability to the environmental remediation plan of the various technological policies that will be proposed in future and to collaborate with the main body of environmental remediation and providing easily-to-understand information to the local residents.

5. Proposal 4: Importance of Local Residents Participation

It is important to always conduct the selection of environmental remediation policies and discussion on the priorities of their implementation with the local residents and local municipalities. For this, it is necessary to establish many occasions and places where questions of the local residents, such as the meaning of radiation monitoring data, effects, and issues of environmental remediation work, or the future prospects based on a technological reasoning, are responded with honesty and explained in a clear manner.

6. Future Plan

We have presented the proposals made by the clean-up subcommittee related to the remediation of the environmental contamination caused by the accident at the power plant. Following is our future action plan. In addition, we wish to plan international conferences and symposiums on environmental remediation in collaboration with other academic societies.

(1) Embody the roles and functions of the Radiation Monitoring Center and Environmental Remediation Center.
(2) Advise the preparation of environmental remediation comprehensive strategies.
(3) Present concrete technological program for stepwise implementation policy and evaluate the various technologies to be proposed in the future.
(4) Actively conduct activities to reflect the opinions of local residents.
(5) Cooperate with international organizations and collaborate with their reviews.

II. Environmental Remediation Following the Accident of Chernobyl Nuclear Power Plant

When planning environmental remediation programs for areas outside the premises of the power plant in future, the knowledge gained from the experience of the Chernobyl Nuclear Power Plant Accident, which caused major radiation contamination, could be useful. International Atomic Energy Agency (IAEA) published a report (STI/PUB/1239) that collected the environmental influence and remediation measures in 2006. We investigated the measures examined and implemented after the Chernobyl Nuclear Power Plant Accident and the results obtained with this IAEA report as the main source. In addition, we compared the local characteristics and contamination situations and will present the important perspectives for future environmental remediation.

1. Comparison of Contamination Situation and Land Usage Situation

The amounts of I-131 and Cs-137 released in the atmosphere during the Chernobyl Nuclear Power Plant Accident were 1.8×10^{18} and 8.5×10^{16} Bq, respectively. Meanwhile, the released amounts of I-131 and Cs-137 after the Fukushima Daiichi Nuclear Power Plant Accident, as published by the Nuclear Safety Commission on April 12, 2011, were 1.5×10^{17} and 1.2×10^{15} Bq, respectively (approximately one-twelfth (1/12) and one-seventh (1/7) of the Chernobyl Accident).

Regarding the land usage of the area around the accident sites, the Republic of Belarus as a whole, which was affected by the Chernobyl Accident, include 43% farmland, 39% forest, and 2% rivers, lakes, and marshes. Meanwhile, the areas where the soil contamination concentration by Cs-137 after the Fukushima Daiichi Nuclear Power Plant Accident were 300 kBq/m^2 or more were used as <5% urban area, <10% paddy field, and <10% other types of farmland. The remaining >75% was forest and mountains (Japanese average is 67%).

2. Environmental Remediation after the Accident of Chernobyl Nuclear Power Plant

(1) Environmental Remediation of Urban Area

At residential settlements, the radioactive materials on the surfaces of roads, buildings, and soils became the source of the radiation exposure of the residents. Between 1986 and 1989, measures such as washing of buildings, cleaning and washing of roads, and removal of contaminated soil were implemented at about 1000 settlements and tens of thousands of houses and buildings, in three countries in the former Soviet Union (Ukraine, Belarus, and Russia). During this time, kindergartens, schools, hospitals, and other frequently visited buildings were prioritized for decontamination. During the decontamination, contamination level of the soil near the wall of the washed building increased.

Table 1 summarizes the decontamination target, measures, and achievable effects discussed in the IAEA report. The decontamination effect obtained by RISO laboratory in Denmark obtained is also shown. It was clarified that measures with decontamination effect of >100 involve the removal of contaminated surfaces, such as changing roofs. The decontamination effect of each measure is mostly above 2. During the Chernobyl Accident, dose rate decreased for about 1.5 to 15 factors in different measurement points depending on the adapted method. However, high cost prevented their application in wider areas, leading to only a

Table 1 Environmental Remediation Technology for Urban Area

Contaminated Surface	IAEA STI/PUB/1239 [1)]		RISO- R-828 [2)]	
	Method	DRRF [*1]	Method	DF [*2]
Wall	Sandblasting	10–100	Sandblasting Changing wall paper	4,5 100
Roof	Spraying Water, Sandblasting	1–100	High-pressure water Spray	2.2
			Changing Roof	100
Garden and Field	Digging up	6	Digging up	4–15
	Removing surface soil	4–10	Removing surface soil	4–10, 28
Road	Sweeping	1–50	Vacuum Cleaner	1.4
	Lining	>100	Crushing and Removal	>100

*1 Dose Rate Reduction Factor: Comparison of dose rate on the target surface before and after the decontamination.

*2 Decontamination Factor: Comparison of contamination concentration on the surface or inside of the target before and after the decontamination.

yearly decrease in the radiation exposure of 10% to 20% in average. Even among the infants and school children who were prioritized, it was 30%. On the contrary, secondary contamination was not observed in the decontaminated areas.

(2) Agricultural Measures

During the first few months after the Chernobyl Accident, contamination by direct adhesion to agricultural crops and contamination of raw milk occurred. Contamination by Cs radionuclide was the most significant contamination at the stage after the early phase. In comparison to the first year, the radiation concentration of grains decreased in the second year. After 1987, high radiation concentration of radioactive Cs was detected in meat and raw milk. Therefore, reduction measures in the radioactive material in livestock products were conducted at collective farms of three former Soviet Union countries.

These measures were mainly: (i) Root improvement through soil cultivation, re-seeding and supply of inorganic fertilizer (nitrogen, phosphorus, potassium), and lime. (ii) Growing rapeseed, which absorbs less Cs, and use it for livestock feed. (iii) Clean-feeding which feeds livestock with less contaminated feed and grass. (iv) Giving Cs binding agent, which reduces the Cs absorption in the digestive organ, to the livestock by mixing it to the feed. Soil treatment, such as root improvement, showed the greatest effect for the first time, and it was influenced by the quality of the soil and its fertility situation. Usage of less contaminated feed showed constant effectiveness. Several types of Prussian blue, used to promote excretion at the time of ingestion of radioactive Cs nuclide, were used as Cs binding agents. In areas, such as Ukraine, where they were not available, clay minerals were used instead.

(3) Measures for Forest and Water Area

In forests, a large quantity of radioactive materials settles due to the filtering effect of the trees, and it is a characteristic that Cs amount in flora and fauna is difficult to reduce due to the recirculation within the ecosystem. Its environmental remediation methods can be roughly categorized into management-based measures through restricted usage and technology-based measures using machines and chemicals.

After the Chernobyl Nuclear Power Plant Accident, following management-based measures were taken. (i) Restriction on entry to the forests. (ii) Restriction on collecting food (mushrooms, berries, and game meat) and firewood. (iii) Warning to avoid hunting during the season when the games are eating contaminated plants. (iv) Preventive measures against the forest fire to prevent secondary contamination to the environment. Besides the three former Soviet Union countries, some of these measures were taken in Scandinavian countries.

However, three former Soviet Union countries faced problems, where restrictions on collecting mushrooms and other restrictions in these areas were not socially acceptable and were ignored by the public. The technology-based measures were deemed unrealistic due to its enormous cost.

The water contamination immediately after the accident was caused by the effect of short half-life nuclide such as I-131. This decreased after time through dilution, decay, and deposition on the soil. In long-term, the outflow of Cs-137 and Sr-90 from the soil and movement of contaminated sediment are slowly continuing. The internal radiation of fishes decreased due to a decay in radionuclides. However, the Cs concentration increased afterward due to the food chain of the creatures in the water system.

The method to collect contaminated soil to prevent the transferring of radionuclides to the water system was not only expensive and ineffective but also caused the radiation exposure of the workers. Moreover, an experiment to spray lime or potassium in lakes to reduce the Cs intake of fishes, as was done in the agricultural measure, was conducted. However, due to the problem of the retention time of chemical substances in water, there was no long-term effect. As a result, it is deemed that there is no effective measure other than the intake restriction of contaminated water and freshwater fishes. Furthermore, no direct measure for irrigation water was taken, and there is no evidence of a request for or application of measures for seawater system because the accident site was far from the Black Sea or the Baltic Sea.

3. Precautions for Considering Environmental Remediation Measures for Fukushima Daiichi Nuclear Power Plant Accident (Through Comparison with Chernobyl)

Among the environmental characteristics, it is necessary to consider the difference in the ratio of the water area that influences the behavior of deposited radioactive materials and areas of forests and mountains where long-term exposure dose reduction policy is important. Regarding agriculture, the habits such as the use of irrigated water for rice farming vary significantly. Moreover, the huge amount of debris and damaged infrastructure due to the earthquake and tsunami, which caused the accident, is a specific problem of this accident. On the contrary, the low-level waste processing, the time required for remediation work, and the costs associated with the protection of the workers from the radiation dose, among others, which were problems also after the Chernobyl Accident, are the issues to be examined and evaluated for the future implementation of the remediation measures.

III. Issues of the Legal System in Implementing Environmental Remediation

We will specify the legal issues related to the clean-up of the surrounding area after the Fukushima Daiichi Nuclear Power Plant Accident.

1. Radioactivity Released During the Accident and its Impacts

First, what was the amount of radioactivity released during the accident? The estimation of the released radioactive iodine and radioactive cesium published by the Nuclear Safety

Commission on April 12, 2011, was 160 thousand terabecquerel (16×10^{16} becquerel).

Following are the main impacts of this released radioactive materials that have been verified so far, and legal measures against them.

(1) High level of radiation was detected in tap water, vegetables, and seafood.

The Ministry of Health, Labor and Welfare set a provisional regulation value for the Food Sanitation Law on March 17, 2011, and restricted the consumption of products that exceeded this standard. On April 5, the provisional regulation value for the radioactive iodine in seafood was added.

(2) Restriction associated with rice plantation in the evacuation area, deliberate evacuation area, and evacuation-prepared areas in case of emergency.

The Ministry of Agriculture, Forestry, and Fisheries instructed to refrain from planting rice in the evacuation areas, deliberate evacuation areas, and evacuation-prepared areas in case of emergency during 2011 FY. The Chief of the Government Nuclear Emergency Response Headquarters (Prime Minister Kan) presented the upper limit of cesium in the soil, stating that the amount of cesium in the plantation may be less than 5000 Bq/ kg.

(3) High radiation was detected also in pasture grass.

The Ministry of Agriculture, Forestry and Fisheries instructed the standard for radioactive materials in a coarse feed to livestock farmers.

(4) Radiation was detected in the wastes.

Neither processing method nor standard limits are set yet.

2. Where the Problem is Located (1) : Waste

The current major problem is the fact that the debris and other wastes contaminated by radioactivity cannot be treated as industrial wastes.

According to the law on industrial wastes (“Waste Management and Public Cleansing Act”) , the definition of waste excludes the radioactive materials and objects contaminated by them.

Reactor Regulation Act (Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors) sets the standard for when an object does not have to be treated as a radioactive waste (clearance level). However, disaster wastes are not wastes produced by nuclear facilities, and therefore inappropriate to apply this standard to them.

This absence of processing method and technological standard for the wastes is becoming a major issue.

The vast quantity of debris and other wastes will be generated. It is estimated that the debris alone will reach approximately 2.9 million tons. In addition, agricultural products, grass, and in some cases, contaminated soil with radioactivity level exceeding the standard limits will also be treated as targets.

3. Where the Problem is Located (2) : Environmental Radiation

The next problem is the absence of a safety standard for environmental radiation for lifting the evacuation order. On April 19, 2011, the Government Nuclear Emergency Response Headquarters provided a provisional standard of 3.8μSv/h for determining the usability of school buildings and schoolyard in the Fukushima Prefecture. This was set so as not to exceed

20 mSv/year, which is the upper limit of the intervention dose standard of 1–20 mSv/year at the convergence stage of an accident set by International Commission on Radiological Protection (ICRP). Later, the Ministry of Education, Culture, Sports, Science and Technology provided an estimation that stated the maximum radiation dose school children can be exposed to be about 10 mSv/year. Note that, due to the many measures are taken afterward, the hourly average radiation dose of each schoolteacher from 55 schools between April 27 and July 3 was 0.2μSv/h. If we assume the exposure to be 8 h per day and 200 days per year, it would amount to 0.3 mSv/year. This was reported on July 21 by the Ministry of Education, Culture, Sports, Science and Technology to the Nuclear Safety Commission.

Currently, the standard for the setting of evacuation areas is 20 mSv/year, which is the lower limit of the recommended amount of 20–100 mSv/year during an accident set by ICRP. In other words, areas where the estimated amount of accumulated dose until March next year based on the observed amount until now exceed this standard are designated to be deliberate evacuation areas.

4. Current State of Waste

The following emergency measures were taken collaboratively on May 2, 2011, by the Ministry of Health, Labor and Welfare, the Ministry of Economy, Trade and Industry and the Ministry of the Environment based on the advice from the Nuclear Safety Commission. (cf. 2011.5.2 the Ministry of the Environment document: "Provisional measures for disaster wastes in Fukushima Prefecture")

- Regarding the evacuation areas and deliberate evacuation areas.

Meanwhile, transportation and processing of disaster wastes have not been launched in these areas. The future actions will be considered in response to the specific situations of the evacuation areas and other areas.

- The waste in the Hamadori and Nakadori regions (excluding the evacuation areas and deliberate evacuation areas).

For the time being, collect wastes in temporary storage without processing. The processing of the contaminated disaster wastes will be considered based on the result of the field study.

- Wastes in the Aizu region.

The disaster wastes in the Aizu region will be processed systematically similar to that before the accident.

- Household wastes and a small quantity of common industrial wastes will be processed with the usual method. Moreover, objects left outside will be treated usually as long as it was not placed there between the accident and late March.

Note that the definition of "disaster waste" is waste that was generated by the tsunami or earthquake. The disaster waste that will be generated in Fukushima Prefecture is estimated to be approximately 2.9 million ton. Measures such as prevention of inhaling dust will be taken for the workers dealing with the disaster waste. Moreover, regarding the collection of disaster wastes, the Ministry of the Environment is scheduled to conduct environmental monitoring of the area around the temporary storage site and will take measures to reduce effects on the surrounding areas as much as possible, such as entry restriction and prevention of dispersion.

5. Wastes to be Generated in Future

A large quantity of radioactive waste is expected to be generated through contamination protective measures in the long-term contamination areas. The source will include cleaning of buildings and improvement of soil and plants. There are areas where cleaning of schoolyards of elementary schools is already being conducted. If contaminated soil is simply buried in the corner of each facility, there is a possibility of secondary calamity during medium to long-term usage of the land. The government must present options for processing methods and safety standard for each method urgently.

6. Issues to be Solved

(1) Protection of Residents Living in the Long-Term Contamination Areas after the Accident.

This will signify the beginning of the reconstruction phase after the accident. Determining the protection standard after the accident will provide people with protection against the potential health effects of radiation and sustainable living condition that includes a stable lifestyle and means of livelihood.

The 2009 ICRP recommendation (Pub 11) brought together the knowledge on this problem globally [3)].

It contains not only the protection against radiation but also the ways of thinking that considers every aspect of daily life, such as environment, health, economy, society, psychology, culture, ethics, and politics, among others. It is especially important that it should be simultaneously conducted with providing the information on environmental remediation or the future policy on measures to be taken such as partial restriction of the lives of the residents and warnings on their daily lives, among others, after sufficient discussion with the relevant parties.

(2) Issues to Consider Regarding the Legal Measures to be taken after the Accident.

It is necessary to shift the management to a collegial system aiming to take individual situation into consideration and to rationally reduce the exposure as much as possible, where the Emergency Response Headquarters make decisions under the strain of urgency after the accident.

It is not appropriate to uniformly estimate the exposure when people are living and working in a contaminated area. The exposure level is mainly determined by individual actions and therefore differs greatly from person to person. Thus, the protection policy should be planned for each individual. It is the national government's responsibility to guarantee the welfare of the society and individuals when approving a group to stay within the contaminated area. It is extremely important for the decision-making on the protection policy to ensure the participation of relevant parties, providing all the important information to the relevant parties and leaving the record of the decision-making process in writing.

IV. Conclusions

The two legal problems related to the clean-up discussed in this study are closely connected to the safety standard of radiation. The environmental radiation standard is especially required to accelerate the early return of the evacuated residents.

The 2009 ICRP recommendation (Pub 11) brought together the knowledge on this problem globally. It is effective to receive advice from specialists who are familiar with ICRP (Pub 111) and to share important information with relevant parties, especially with the residents of the contaminated areas.

Through this, it is essential to plan concrete protection policies, set rationally achievable protection standard, and propose and execute concrete roadmap toward the lifting of the evacuation order. It is required for a specialist to prepare waste processing method and safety standards along with this plan.

References

1) IAEA, STI and PUB and 1239. 2006.
2) RISO, RISO R 828 EN. 1995.
3) International Commission on Radiological Protection (ICRP) Recommendations (Pub 11). 2009.