Technical Strategic Plan 2024 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.

Overview

September 27, 2024

Nuclear Damage Compensation and
Decommissioning Facilitation Corporation

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1. Introduction

The long-term approach to the decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc. (hereinafter referred to as the “Fukushima Daiichi NPS”) has proceeded under “the Mid-and-Long-term Roadmap towards the Decommissioning of Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.” (hereinafter referred to as “Mid-and-Long-term Roadmap”), developed by the Japanese Government. At present, trial retrieval of fuel debris has started, efforts toward full-scale decommissioning work that will begin in Phase 3-[1][1] are being implemented with the cooperation of the relevant organizations. Fig.1 shows the division of roles of related organizations responsible for the decommissioning of Fukushima Daiichi NPS.

Nuclear Damage Compensation and Decommissioning Facilitation Corporation (hereinafter referred to as “NDF”) has supported efforts related to the decommissioning of the Fukushima Daiichi NPS as an organization that conducts research and development, as well as provides advice and guidance, required for decommissioning since 2014. This “Technical Strategic Plan for Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station” (hereinafter referred to as the “Technical Strategic Plan”), as a part of these supports, has been compiled annually since 2015 with the following objectives.

- Providing a solid technical basis for the Mid-and-Long-term Roadmap and contributing to its smooth and steady implementation, consideration of revisions, and
- Providing a basis for “The Policy for Preparation of Withdrawal Plan for Reserve Fund for Decommissioning”

In addition, since the “Measures for Mid-term Risk Reduction at TEPCO’s Fukushima Daiichi NPS” (hereinafter referred to as “Target Map for Reducing Risks”) formulated by the Nuclear Regulation Authority (NRA) takes into account the process specified in the Mid-and-Long-term Roadmap, the Technical Strategic Plan will also contribute to achieving the goals set forth in the Target Map for Reducing Risks.

[1] Period from the end of Period 2 to the end of 2031 as specified in the Mid-and-Long-term Roadmap

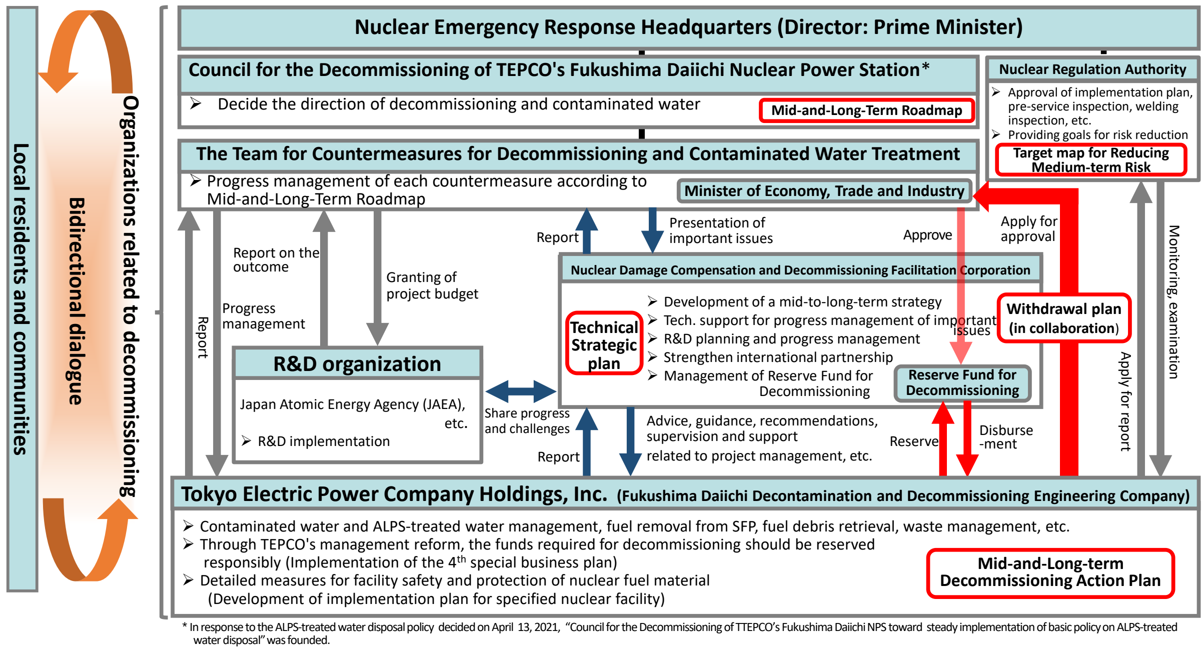


Fig. 1 Division of roles of related organizations responsible for decommissioning of the Fukushima Daiichi NPS

2. Concept for reducing risks and ensuring safety in the decommissioning of the Fukushima Daiichi NPS

2.1 Basic policy for the decommissioning of the Fukushima Daiichi NPS

The basic policy for decommissioning the Fukushima Daiichi NPS is “to continuously and quickly reduce the risks arising from the radioactive materials caused by the accident that do not exist in normal nuclear power plants.” In addition, ensuring the safety of decommissioning work requires measures from a long-term and comprehensive perspective on the balance of risks based on safety characteristics. It is also important to consider flexible risk reduction strategies.

2.1.1 Matters to be discussed in Phase 3

In March this year, the Sub-Committee for the Evaluation of Fuel Debris Retrieval Methods (Chairperson: Toyoshi Fuketa, previous Chairman of Nuclear Regulation Authority) established under NDF’s Decommissioning Strategy Committee suggested methods for large-scale fuel debris retrieval that is to start in the first half of the 2030s targeting Unit 3, and TEPCO initiated specific design studies. TEPCO is to proceed with the design studies, report the progress to the Sub-Committee, and present the future prospect in one to two years.

In September this year, trial retrieval of fuel debris started in Unit 2. Collected samples will contribute to the severe accident progression analysis through analysis and characterization, and the findings will be reflected on the design studies by TEPCO towards large-scale debris retrieval, as necessary.

Retrieval of fuel debris is the most important task for the decommissioning of the Fukushima Daiichi NPS in terms of both risk reduction and technical challenge. Finally, 13 years after the accident, the decommissioning of the Fukushima Daiichi NPS enters a new stage toward the retrieval of fuel debris.

Fuel debris retrieval will have to be advanced step by step in a severe high radiation dose environment, through highly difficult remote operations, while placing utmost priority on safety. This is an unprecedented technical challenge, and TEPCO needs to collaborate with contracting companies at each stage of survey, design, construction, retrieval work, review, and management to accomplish the never-done-before feat.

Retrieved fuel debris will in principle be placed in safe containers and temporarily stored on the premises of Fukushima Daiichi NPS. First, debris samples will have to be characterized and analyzed to determine the technical storage conditions and will be placed in a stably stored state while steadily proceeding with the retrieval work.

The specific method and timing of processing and disposal to come after that will be studied after characterization and analysis of the fuel debris to be retrieved and stored are complete. For that reason, for the ideal disposal method, specific technical requirements will be presented in the

Technical Strategic Plan once fuel debris retrieval, analysis, and studies have progressed to a certain degree.

In the new stage heading for fuel debris retrieval, it is important to share the technical prospects of the decommissioning, including issues and difficulties, with local residents and communities while working on the project. Instead of unilaterally disseminating information on the decommissioning, the concerns and anxieties of local residents need to be listened to and reflected in the decommissioning. Honest and transparent dialogs with local communities covering various topics including not only fuel debris retrieval but also other technical initiatives and future image will have to be continued until understanding is gained.

For these dialogs, it is necessary to determine how they should be carried out as early as possible and be continually reviewed. Dialogs need to be repeated through various channels such as municipalities, committees, industry organizations and media, but all relevant personnel must never forget that who they must talk with primarily are all of the local residents.

NDF held sessions of direct dialogs with local residents at 13 municipalities for the first time after the accident and exchanged opinions regarding the report issued by the Sub-Committee in March this year. Some opinions and questions received at the sessions were rather scathing, but it was made known to NDF that such opportunities were strongly desired by local residents in general and dialogs should be continued while making improvements. From this experience, NDF believes that direct dialogs are one of key channels. In overseas cases, some say repeating such town hall meetings is the very essence of dialog. NDF plans to continue direct dialogs with local residents about twice a year.

2.1.2 Risks management to be addressed in Phase 3-[1]

Regarding fuel debris retrieval, in Phase 3-[1] preparations for further expansion of the retrieval scale, which will be full-scale decommissioning work, will be made. Though the current state of temperature and pressure inside the Primary Containment Vessels (hereafter referred to as PCVs) is stable, conditions will change with the start of fuel debris retrieval. Thus, it is undeniable that risks previously perceived as minor or unknown may become apparent. To effectively respond to risks toward further expansion of the retrieval scale, the issue is to improve the ability to observe conditions inside the PCVs where changes in these risks are most likely to occur. Therefore, consideration should be given to expanding the type and number of monitoring targets, while taking into account the current purpose of the monitoring parameters and the number of monitoring devices in the PCVs and difficulties in on-site operation.

2.2 Concept of reducing risks caused by radioactive materials

2.2.1 Quantitative identification of risks

The Technical Strategic Plan uses a method based on the Safety and Environmental Detriment score (SED) developed by the Nuclear Decommissioning Authority to express the magnitude of risk (risk level) posed by radioactive materials. In this method, the risk level is expressed by the product of "Hazard Potential", an index of the impact of internal exposure by intake of radioactive materials into the human body, and "Requiring Level for Safety Management[2]", an index of the likelihood of an event occurring. The current risk levels assigned to the respective risk sources are expressed in Fig. 2 with "Hazard Potential" and "Requiring Level for Safety Management" as the axes[3].

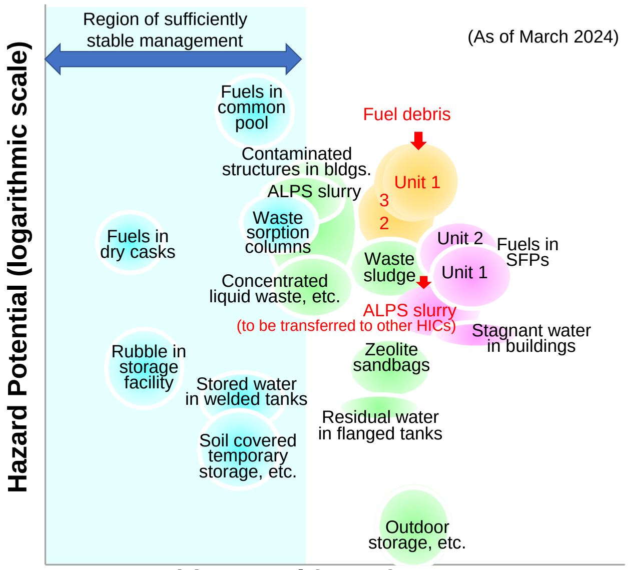


Fig. 2 Risk levels posed by major risk sources at the Fukushima Daiichi NPS

The writings in red in Fig. 2 present the risk sources that have changed significantly from the evaluation of the Technical Strategic Plan 2023 (as of March 2023), the origin of the arrow indicates the location reported in the Technical Strategic Plan 2023.

ALPS slurry (to be transferred to other HICs) was moving downward because Hazard Potential of shifted ALPS slurry (green) has decreased as the progress of the transfer operation. Note that there is little variation in the ALPS slurry (green) on a logarithmic scale, since the shifted percentage of the Hazard Potential of ALPS slurry (green) to the original ALPS slurry (green) is small. Hazard Potential of fuel debris decreased and moved downward as a result of the re-evaluation of the changes in the hydrogen concentration after the suspension of nitrogen filling, which affects the time allowance (a factor of Hazard potential) considering the radioactivity decay and the distribution of fuel debris, and the evaluation of a more certain state of extended time allowance than previously assumed. Regarding the impact on the Requiring Level for Safety Management for fuel debris and contaminated structures etc., in the buildings" based on the partial loss of concrete in pedestals found by the PCV internal investigation of Unit 1, although there are uncertainties in the evaluation

[2] An indicator of the long-term stability and handleability of the risk source depending on the sufficiency of the containment function of the facility containing the risk source and the characteristics (degradation, activity level), etc., of the risk source

[3] The Requiring Level for Safety Management is expressed by the product of FD (Facility Descriptor, an index indicating the sufficiency of the confinement function) and WUD (Waste Uncertainty Descriptor, an index indicating long-term stability). In the previous evaluation of FD and WUD, the evaluation was performed by applying the risk source to be evaluated to the combination of 10 types of descriptions (categories) that explain the nature of the risk source prepared in advance and scores. The evaluation method is being improved so that the judgment and recognition of the evaluator for the risk source by individual evaluation viewpoint can be directly expressed in the Requiring Level for Safety Management without depending on the category classification prepared in advance in the future.

conditions, it was evaluated that the structural integrity bearing the load applied from the pedestal superstructure would be maintained at the time of an earthquake equivalent to Ss900. In an event assuming that the RPV has fallen, and a large opening was created on the PCV as a result of loss of the supporting function of the pedestal, the effective radiation dose at the site boundary is below 5 mSv/event, the standard at the time of the accident. Therefore, it was evaluated that there is no change in the Requiring Level for Safety Management.

2.2.2 Risk reduction strategy

2.2.2.1 Interim targets of the risk reduction strategy

Measures for risk reduction include the reduction of the "Hazard Potential" and the reduction of the "Requiring Level for Safety Management", reduction of the "Requiring Level for Safety Management" is generally considered to be easily realized from an engineering perspective. The immediate goal, therefore, is to reduce Requiring Level for Safety Management by the methods described above and bring it into a "sufficiently stable management" (Fig. 2) region that is equal to or lower than the level of facilities that are not affected by the accident or facilities that were designed after the accident to allow for a long-term storage. The process to bring it into a "sufficiently stable management" region and the progress of decommissioning work in line with that process are shown in Fig. 3. "Requiring Level for Safety Management" can be expressed as the product of two factors: one pertaining to the sufficiency of the containment function of the facility that contains the risk sources (hereinafter referred to as "containment performance"), and the other pertaining to the long-term stability and handleability of the risk source, such as its characteristics (degradation and activity level), packing, and monitoring conditions. As this method to reduce the likelihood of an event expressed in "Requiring Level for Safety Management", the first is to improve the containment performance of the facilities that contain risk sources. The second is to improve long-term stability by reducing uncertainty in handling risk sources and by enabling long-term and stable management based on the characteristics of risk sources.

Fig. 4 shows the transition of Requiring Level for Safety Management corresponding to risk sources and their treatment process indicated in the flow graphically by risk source category. The Requiring Level for Safety Management shown is divided into two components, one for containment performance and the other for long-term stability, which correspond to the methods for reducing the Requiring Level for Safety Management described above. This will help determine whether containment performance or long-term stability measures should be prioritized to bring the risk source into the "Sufficiently stable management" region. In addition, in the processing process that is the scope of a future or ongoing study in the flow, the blue and orange arrows indicate what needs to be improved to bring the level of Requiring Level for Safety Management into the Sufficiently Stable Management region (in the pale blue area in the graphs).

Specific risk reduction strategies for each source are detailed in Chapter 3.

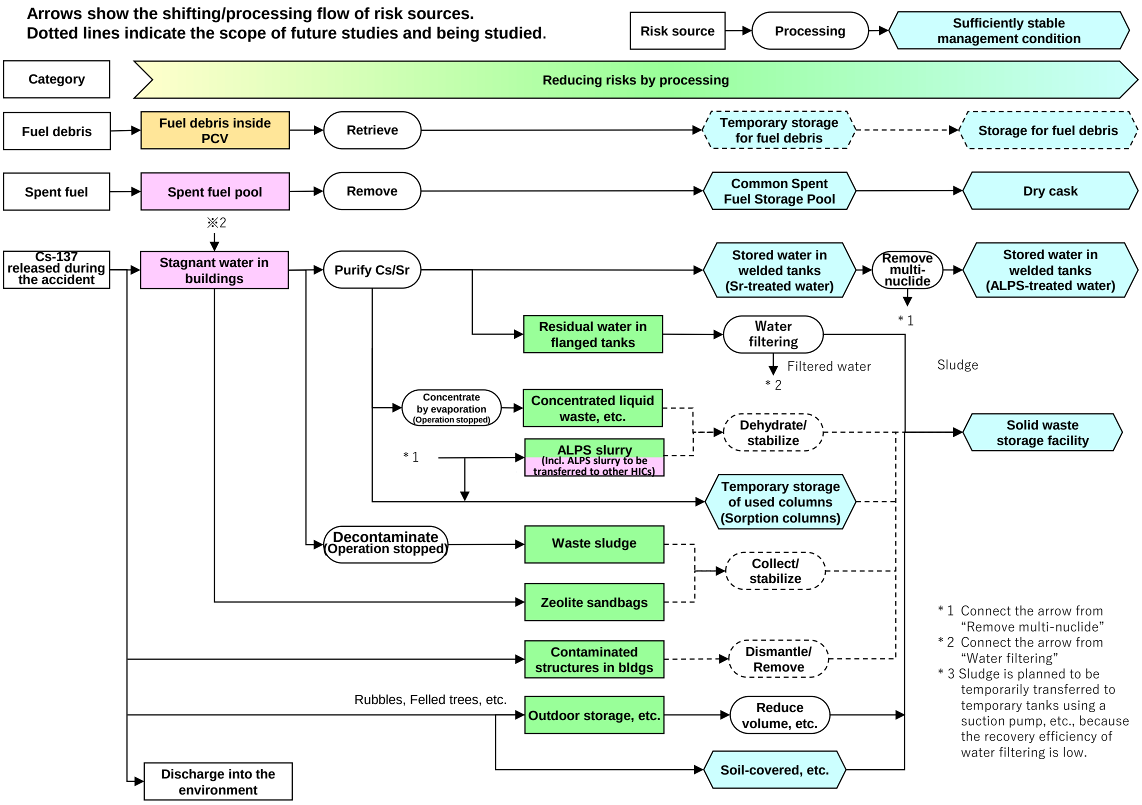
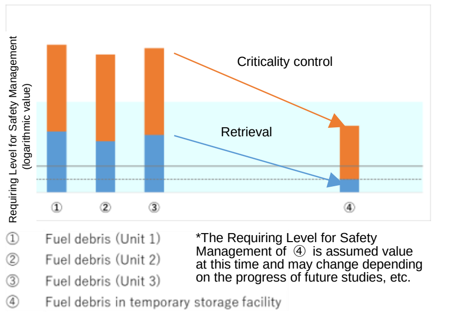
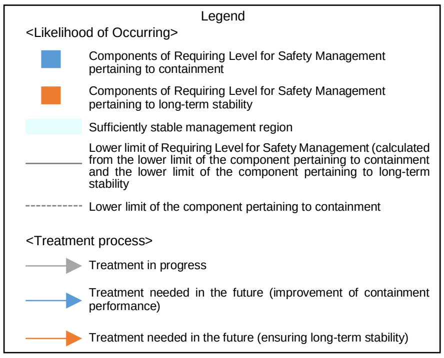
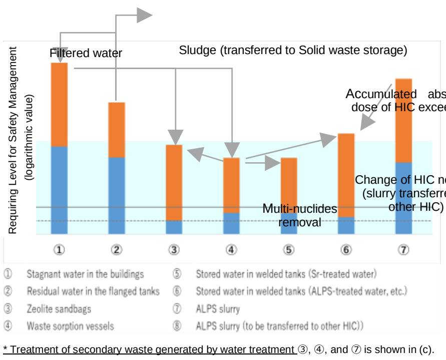


Fig. 3 Risk reduction process for major risk sources and the progress (as of March 2024)



(a) Fuel debris





(b) Contaminated water

(c) Secondary waste generated by water treatment

Fig. 4 Changes in Requiring Level for Safety Management for major risk sources

2.2.2.2 Basic approach to risk reduction

There are still significant uncertainties in decommissioning the Fukushima Daiichi NPS. Eliminating these uncertainties requires many resources and, in particular, a considerable amount of time. However, to realize prompt risk reduction, it is necessary to promote the decommissioning work while ensuring safety as the top priority by making comprehensive decisions based on the knowledge obtained, even though uncertainties remain to a certain extent. Regarding the perspective from which these comprehensive decisions will be made, NDF summarizes the following five guiding principles:

(Five guiding principles)

・ Safe	Reduce the risks posed by radioactive materials and ensure work safety
・ Proven	Use highly reliable and flexible technologies
・ Efficient	Use resources effectively (e.g., people, things, money and space)
・ Timely	Be conscious of time
・ Field-oriented	Comprehensive three-realities policy (by checking actual site, actual things, and actual situation)

In applying the five guiding principles to the actual site, it is important to proceed with the decommissioning operation after greatly emphasizing safety assurance for the purpose of protecting human beings and the environment from the radioactive materials associated with the operations, thoroughly conducting radiological impact evaluations, and taking appropriate radioprotective measures (Safe).

In the decommissioning of the Fukushima Daiichi NPS, because the public risk level is rising with time as the degradation of facilities damaged by the accident progresses, controlling this risk to be as low as reasonably achievable (Proven, Efficient) as promptly as possible (Timely) in light of the situation at the site, and proceeding with the decommissioning in a reliable manner by feasible ways in the harshest on-site state (“Field-oriented”) will lead to ensuring safety in the medium-to-long-term.

As for the result judged based on these guiding principles, it is also important to work to disseminate information carefully so that the results will be widely accepted by society.

2.3 Approach to ensuring safety during decommissioning

2.3.1 Basic policy for ensuring safety based on the characteristics of Fukushima Daiichi NPS

The decommissioning of the Fukushima Daiichi NPS that contains the reactors involved in the accident is an unprecedented activity taking place in a peculiar environment different from that of a normal reactor, and therefore, to ensure safety, the issue is to sufficiently consider the following characteristics (peculiarities) regarding safety:

- A large amount of radioactive material (including α-nuclides that have a significant impact on internal exposure) is in an unsealed state, as well as in unusual (atypical) and various forms.
- Barriers for containing radioactive materials, such as reactor buildings and PCVs, are incomplete.
- Significant uncertainties exist regarding the state of these radioactive materials and containment barriers, etc.
- It is difficult to access the site and install instrumentation devices to obtain on-site information due to constraints such as high radiation levels on site.
- Since the current level of radiation is high and further degradation of containment barriers is a concern, it is necessary to take measures in consideration of the time axis without prolonging the decommissioning activities.
- On the other hand, more than 10 years have passed since the accident and the intrinsic energy (decay heat) is small and the state change is slow, so there is a large time margin that can be allocated for convergence of abnormal conditions such as failures.

Therefore, in proceeding with decommissioning work, Tokyo Electric Power Company Holdings, Inc. (hereinafter referred to as “TEPCO”) needs to consider the following points with particular attention, based on the five guiding principles.

First, with regard to "safe," when considering decommissioning work, a wide range of possibilities (cases) should be assumed, fully taking into account the above-mentioned special characteristics, it is a prerequisite to making sure that the safety can be ensured. Based on this premise, it is necessary to comprehensively improve safety from the following perspectives: (I) to what extent safety will be ultimately improved by decommissioning, (ii) how long it will take to achieve that, and (iii) how much safety will change as a result of the work.

Second, with regard to “field-oriented”, it is essential to reflect the information obtained from the actual site in engineering appropriately, because there is a limit to the response by design alone due to large uncertainties. In order to reliably implement unprecedented engineering such as fuel debris retrieval, it is important to value the viewpoints and senses of people and organizations (operators) who are directly involved in the actual site work and familiar with the site, and to respect the viewpoints and judgments that are directly addressed at the site (hereinafter referred to as “the operator’s perspective”). Moreover, in promoting long-term decommissioning, it is necessary to maintain and strengthen the operator's viewpoint and sensibility, TEPCO itself should take over the operator's perspective.

In the actual study of the decommissioning work, it is essential for TEPCO to define the requirements to satisfy regulatory demands for the work, and to consider specific safety measures to achieve them, while applying the safety perspective and the operator’s perspective. In this decommissioning work with significant uncertainties, however, it is frequently difficult to uniquely define requirements and the equipment/operational specifications that will satisfy those requirements. Even in such cases, the decommissioning work should be carried out flexibly and promptly by verifying and improving the selected, specifical safety measures with the “preliminary implementation and utilization of the obtained information in the latter stages” and “iteration-based engineering[4]”.

2.3.2 Preliminary implementation and utilization of the obtained information in the latter stage

Because of the high uncertainty surrounding the Fukushima Daiichi NPS, it is necessary to assume extremely large safety margins and a wide range of technological options. In addition, considering the further deterioration of containment barriers and other factors, it is necessary to immediately improve the state of risks and reduce uncertainties. Therefore, after addressing “operation at first stage” where practical safety can be ensured, it is important to make efforts to reduce large uncertainties in the entire decommissioning process by implementing “sequential type approach” to develop the information obtained there to the next stage.

2.3.3 Approach to address a temporary increase in risk level associated with decommissioning operations

While the decommissioning work is striving for prompt risk reduction from a medium-and-long-term perspective, careful deliberation of the possibility that the performance of decommissioning work may temporarily change the risk levels and may increase the radiation exposure of workers is required.

2.3.3.1 Safety functions that need to be enhanced in view of the two problems that occurred in FY 2023

In FY 2023, two major problems occurred, namely, “physical contamination during the cleaning of additionally installed ALPS piping” (October 25, 2023) and “leakage of water containing radioactive materials from the High-incinerator building” (February 7, 2024). These cases involved unintended leakage of radioactive materials, primarily arising from human errors. As a result, the workers were exposed to radiation in the former incident, and workers nearby were put at risk of being exposed to radiation in the latter incident.

What is commonly observed in these two problems is that the leaked radioactive materials did not reach the site boundary because the energy to spread the radioactive materials was small, and workers nearby were put at risk of being exposed to radiation.

This indicates that, while reducing exposure risk at the site boundary is a given, consideration needs to be given to changing or reinforcing equipment that bears the containment function, while placing higher priority on reducing exposure risk for employees who perform patrols or inspection of such equipment and for nearby workers.

[4] A method of gradually increasing the level of completion of engineering by finding the next result based on a certain result and repeating this cycle.

2.3.3.2 Importance of worker safety

Improving safety of workers including reduction of radiation exposure risk is by itself “Safe” of the Five Guiding Principles and important. “Safe” was insufficient in the two incidents as a result. We have to say that “Field-oriented”, to complement “Safe”, was also insufficient, considering that the main cause of the two incidents was human error by workers. If an incident to lose “Safe” occurs during work, the need arises to address the issue. Automatically, the work or related work will have to be delayed, and “Timely” will be lost. If events like this continue to occur, an excessive amount of resources may have to be allocated to address such issues. That may go against the principle “Efficient”.

As stated above, when worker safety is compromised, it can lead to a situation where the majority of the Five Guiding Principles are not being met. Conversely, as stated in 2.3.3.1, at workplaces that involve use of energy in small amounts (i.e., force to drive dispersion of radioactive materials is small), design and operation focusing more on the reduction of workers’ radiation exposure risk would ensure decommissioning work based on the Five Guiding Principles.

2.3.4 Common tasks that became apparent from a series of problems

Multiple incidents occurred in series since the “physical contamination during the cleansing of additionally installed ALPS pipes” incident. TEPCO judged the necessity of analyzing the common factor of the incidents, conducted a review process of i. Understanding the facts → ii. Direct causes → iii. Organizing the background factors → iv. Analysis of common factors → v. Proposals for improvement measures, and identified the following common factors based on the background factors extracted.

- Common factor ①: [Facility design stage/facility operation stage] Vulnerability of facilities to risks to people and the environment
- Common factor ②: [Work preparation phase] Insufficient identification of hazards, risk scenario setting and risk assessment, preliminary safety assessment, and consideration of safety measures and protective actions for the work
- Common factor ③: [Work implementation stage] Lack of understanding of the actual situation at TEPCO and main contractor sites, and lack of crisis awareness

Based on the common factors identified by TEPCO, NDF sorted out the following common issues.

- Common Task ①: Further enhancement of risk assessment
- Common Task ②: Further enhancement of the understanding and management of on-site situations in the multilayered subcontracting system

(1) Initiatives to address Common Task ①

The lessons learnt from the series of problems above are the need for having the ability to identify, analyze, and assess risks according to the state of the worksite that constantly changes, and the importance of heightening the risk sensitivity to attain that.

TEPCO had been conducting risk assessments jointly with prime contractors, but they learned from the series of problems that such assessments were not good enough. TEPCO needs to further reinforce its initiatives to heighten the risk sensitivity of all personnel working at the Fukushima Daiichi NPS by involving its employees, prime contractors, and workers at the front line on site.

(2) Initiatives to address Common Task ②

All of the incidents above occurred under the multilayered subcontracting system for construction work (hereinafter referred to as “multilayered subcontracting structure”). NPSs handle radioactive materials and any problem at an NPS will have an enormous social impact if it occurs, and power companies are required to manage the worksites more strictly than others. In addition, the Fukushima Daiichi NPS, the very site of the accident, needs to have much stricter worksite management than any other nuclear power station.

For this reason, TEPCO will have to change its relationship with the subcontractors, that is, partner companies, into a more cooperative relationship based on the multilayered subcontracting structure in Fukushima Daiichi NPS. The relationship between TEPCO and partner companies recommended by NDF will be stated in “6.1.2.2 Consideration about site management in coordination with partner companies” below.

The decommissioning of the Fukushima Daiichi NPS needs to be promoted with the broad understanding of not only the government, NDF, TEPCO, and others, but also of a wide range of people, including local residents. In particular, it is important to establish a system for continuous risk monitoring that is easy to understand for a wide range of people regarding risk reduction strategies for decommissioning work, safety assurance of decommissioning operations, and how the site-wide risk reduction is continuously progressing through decommissioning work, and to disseminate these information to society.

In addition to sharing the status of risks regard to the decommissioning of the Fukushima Daiichi NPS through the Technical Strategic Plan on a constant basis, NDF is considering providing the risk reduction process along with the progress of the decommissioning work. TEPCO also needs to develop a mechanism to identify risks for the entire site and become aware of the need to take action to communicate the status of risk reduction to society in an initiative-taking manner.

3. Technological strategies toward the decommissioning of the Fukushima Daiichi NPS

3.1 Fuel debris retrieval

3.1.1 Target

- Retrieve fuel debris safely after thorough and careful preparations, and bring it to a state of stable storage that is fully managed.
- For the trial retrieval (internal investigation and fuel debris sampling) in Unit 2, the first fuel debris retrieval has been launched in September 2024. The future course of action includes internal investigations and a series of operations such as gradual expansion of fuel debris retrieval to acquire knowledge and experience necessary for further expansion of the retrieval scale.
- Moreover, the method of further expansion of the retrieval scale, including those for containing, transferring, and storing of fuel debris, is determined through the assessment of fuel debris retrieval in Unit 2, internal investigations, research and development, and the on-site environmental improvement, etc.

3.1.2 Progress

Unit 1:
In addition to information of the basement floors obtained by investigation using a submersible boat-type access investigation vehicle (hereinafter referred to as “submersible ROV”) performed up to FY 2023, PCV internal investigation (dry area surveillance) was carried out in February and March 2024 mainly for the first floor, which gave visual information on the state of existing structures, deposits, fallen objects, and other matter inside and outside the pedestal. In this surveillance, a small wireless drone and a serpentine robot (equipped with a wireless relay and placed at PCV penetration X-2) were inserted into the first floor inside the PCV through the PCV penetrating part X-2 (hereinafter referred to as “penetration X-2”) to visually inspect the state at the south and north sides outside the pedestal. Further, a small wireless drone was inserted into the pedestal through the opening used to replace the CRD to visually inspect. The key information obtained by this surveillance is as follows. ① It was confirmed that no major damage was present on the outer wall of the pedestal, existing structures were mostly intact, and no noticeable obstructions were present around the CRD replacement rails. ② A fallen CRD housing was partially blocking the opening for replacement in the pedestal. Lumpy objects were observed adhered above the opening, indicating that the housing fell from the above. ③ No major damage was found on the inner wall of the pedestal, and existing installations such as a cable relay box and the existing TIP (Traversing In-core Probe) opening were observed. This surveillance demonstrated that small wireless drones can be used not only outside but also inside the pedestal and provide a substantial amount of visual information albeit limited by the duration of flight. Small wireless drones were found to be useful in PCV internal investigation, and the outcome of this investigation will be reflected on future PCV internal investigation plans for Units 1 to 3, including measures to address issues newly identified.

Unit 2:

The arm-type access equipment (hereinafter referred to as “robot arm”) to be used in trial retrieval has been undergoing performance confirmation tests, verification tests in a simulated environment of an actual machine (hereinafter referred to as “mock-up tests”), and training. So far, function confirmation tests on the robot arm alone have been completed, and confirmation tests in a state of the robot arm being incorporated inside an enclosure are currently in progress. Since the actual work will require repeated access to narrow sections using robot arms, the control program will be optimized to avoid contact during the work and confirmation tests will be continued. In addition, as preparatory work on-site, installation of the isolation chamber for the hatch opening of the existing PCV penetrating part X-6 (hereinafter referred to as “penetration X-6”) was completed in April 2023. In the hatch opening work performed after that, the hatch bolt was found to be adhered. However, removal of the bolt was completed in October, and the hatch was opened. Since then, removal of deposits inside the penetration X-6, removal of the CRD rail guide, and cable push-in operations were completed in May. Installation of the penetration X-6 connection structure and connecting tube were completed in June.

In addition to the uncertainty of on-site operations, since the robot-arm requires time to prepare for access to the pedestal and a certain amount of time to continue testing to confirm reliability, TEPCO took a policy to accomplish early and assured sampling of fuel debris for its characterization first. To that end, with the aim of applying the robot-arm to the site while the verification work continues, sampling of fuel debris was started in September, 2024 by preparing a new telescopic-type device (a device with a mechanism that can change its total length of the device by pulling out or storing a combination of cylinders of different sizes. Hereinafter referred to as "telescopic device") that has been used in similar structures in past internal investigations. In the future, internal investigations and fuel debris sampling with the robot-arm will also be continued as planned. By introducing the robot-arm, debris sampling is planned in the pedestal in a wider area than the telescopic device.

Unit 3:

The concepts for further expansion of the retrieval scale have been studied in advance. Among them, the partial submersion method, the partial submersion method option (solidification/fill method), and the submersion method were selected as candidates. In addition, since February 2023, through decision at the Decommissioning Strategy Committee of NDF, the Sub-Committee for the Evaluation of Fuel Debris Retrieval Methods has been established under the Committee, where the technical feasibility and other aspects of each fuel debris retrieval method are comprehensively studied and evaluated, while placing the utmost priority on safety, and recommendations are made on which method a design study shall proceed at the moment. TEPCO is promoting specific design studies based on the recommendations.

3.1.3 Key issues and technical strategies

3.1.3.1 Fuel debris retrieval strategies in each Unit

Common:

- There are many areas where direct visual information is not available for each Unit, and it is a challenge to promote further internal investigation and obtain various kinds of information. Work will be carried out by formulating/updating the future plan for internal investigation, incorporating new investigation technologies that will be developed assuming further expansion of the retrieval scale. In particular, as it has been demonstrated that wireless drones are extremely accessible and useful surveillance tools, their use, including submersible ROV, will be expanded. The direction of the fuel debris retrieval strategy should be ascertained on the basis of the acquired information in order to avoid engineering backsliding and to increase the reliability of the method chosen.
- Regarding on-site problems experienced so far, measures for preventing recurrence should be reflected in the next work. In addition, methods that can eliminate assumed risks should be developed, and if the risks cannot be eliminated, countermeasures should be prepared in advance.
- Methods that enable retrieval even if all on-site conditions cannot be identified, and other methods (robust methods) not easily affected by external events such as earthquakes

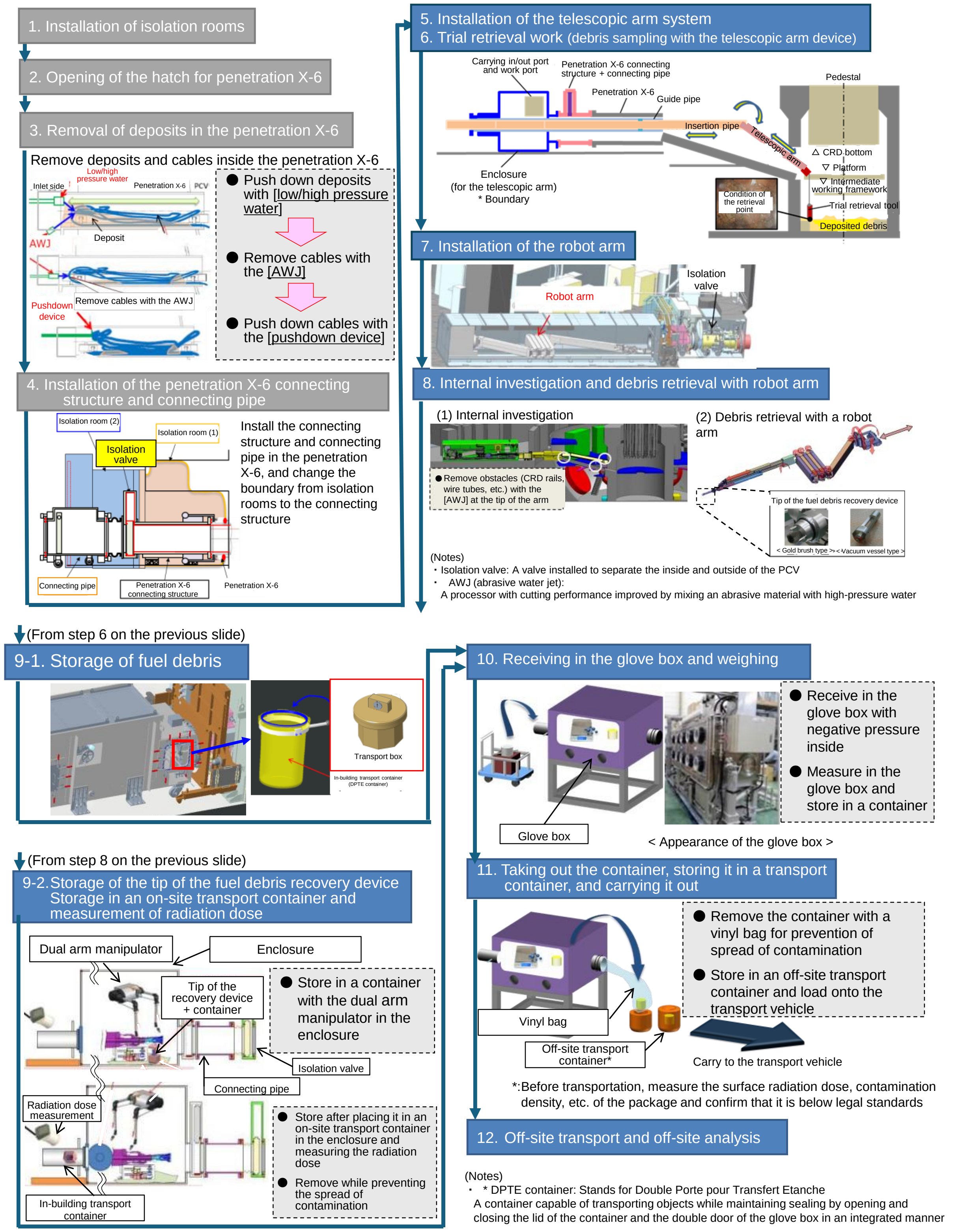
	should be examined while taking into account on-site conditions such as damage to facilities and installations.
•	Efforts should be made to prevent the concentration of worker radiation exposure on specific individuals, reduce the exposure of all workers, and secure human resources from a long-term perspective.
Unit 1:	
•	Toward further expansion of the retrieval scale, studies on retrieval methods will be promoted by taking into account the on-site information and the knowledge gained so far and to be gained in the future, such as from the trial retrieval from Unit 2, the gradual expansion of fuel debris retrieval, research and development, the engineering for applying the R&D results on-site, and the results of the PCV/Reactor Pressure Vessel (hereinafter referred to as "RPV") internal investigation.
Unit 2:	
•	Trial retrieval will be promoted to lead to a gradual expansion of fuel debris retrieval.
Unit 3:	
•	Considering that the removal of fuel in SFP has been completed and there is little interference with other operations, and the working environment of the reactor building will be improved earlier than Unit 1, the technical feasibility, etc., of retrieval scenarios and methods are being examined for further expansion of the retrieval scale ahead of other Units based on the recommendations by the Sub-Committee.

3.1.3.2 Trial retrieval (internal investigation and fuel debris sampling)

The trial retrieval in Unit 2, is intended to access the inside of the pedestal from outside the PCV for further internal investigations and collect small amount of fuel debris. This is because the effort is of great significance, entering a new phase, in which the containment barrier outside the PCV is extended by opening the hatch of the existing penetration X-6 on the PCV, a series of work tasks should be implemented in a phased manner. (Fig. 5). The information obtained from this effort will be used for subsequent gradual expansion of fuel debris retrieval and further expansion of the retrieval scale. In addition, since this will be the first fuel debris retrieval at the Fukushima Daiichi NPS, the experience gained during the process from the examination to the retrieval operation and the information obtained through the analysis of the retrieved samples will be used in future decommissioning efforts. It is necessary to proceed with the work safely and carefully, assuming the possibility that the work may not go as planned due to the uncertainty of the conditions inside the PCV. It is important to utilize the valuable information, experience, etc., gained through them in subsequent retrieval operations including for other Units.

Considering the factors including the uncertainty of on-site operations, robot arm operations requiring time to establish access routes, including cutting and removal of any possible interference with the robot arm in the access route as discovered by mockup tests, verification of reliability of robot-arm requiring a certain amount of time for continuing tests, and TEPCO adopted a policy to accomplish early and assured sampling of fuel debris for its characterization first. For that reason, fuel debris sampling was launched with a newly prepared telescopic device that was used for a similar structure in past internal investigations in September 2024, aiming at applying it to the actual worksite while continuing verification of robot arms. After that, as per the initial plan, TEPCO decided to perform internal investigations and fuel debris sampling using robot arms. The introduction of robot arms is expected to realize sampling fuel debris from a wider area in pedestals than telescopic devices can manage.

In the construction of the access route at the site, events different from those assumed in advance occurred, and it took a considerable amount of time to install the isolation chamber, remove the hatch bolts and nuts of the penetration X-6, and open the hatch. In order to flexibly respond to such events that differ from the prior assumptions, it is important to prepare in advance for the occurrence of unexpected events, such as by identifying and minimizing them in a broad range and then formulating a response policy for unexpected events that may still occur. Moreover, it is also important to be prepared in advance, including reflecting the past on-site work exposure results in the exposure dose plan for future work.



(TEPCO material edited by NDF)

- The analysis results will be used for subsequent gradual expansion of fuel debris retrieval and further expansion of retrieval in scale.

Fig. 5 Work steps of trial retrieval (internal investigations and fuel debris sampling)

3.1.3.3 Gradual expansion of fuel debris retrieval

The gradual expansion of fuel debris retrieval is being prepared in Unit 2 for the period until further expansion of the retrieval scale begins. Its main objectives are to verify the retrieval equipment, acquire data on the environmental impact during the retrieval operation, increase the amount of retrieval, obtain data on fuel debris composition and properties from more samples, and accumulate the retrieval experience of workers.

(1) Retrieval equipment

The retrieval equipment to be used for the gradual expansion of fuel debris retrieval (hereinafter referred to as “robot-arm”) will be improved by increasing the payload and enhancing accessibility, based on the improvements identified during the verification phase of the equipment for trial retrieval. The plan is to expand the range of retrieval while making achievements, starting with retrieval of fuel debris that can be gripped and sucked, and expanding to fuel debris retrieval with cutting. Consideration will also be given to the possibility of cutting platform beams and the range of cutting. Shielding and preventing the spread of contamination are considered for the enclosure containing the robot arm to take in fuel debris.

In addition, because the manipulator to be installed in the enclosure performs various operations and maintenance, it is necessary to ensure the repeatability of tasks and train operators. Moreover, the work period is in the order of several years. Thus, in addition to periodic maintenance, preparation in case of failure is a challenge. Since the radiation dose in the reactor building, where the enclosure will be installed, is high and it is difficult to perform maintenance there. Therefore, the plan is to construct a maintenance building outside the reactor building and equipment/devices or the entire enclosure will be transferred there, then decontamination, dismantling, repair, or replacement will be conducted inside it. The issue is to leverage the experience gained through the maintenance of equipment/devices for further expansion of the retrieval scale. Therefore, a system that can reliably preserve maintenance records, including failure histories and corresponding measures, should be established. NDF will continue to grasp and check the status regarding the technological development of retrieval equipment and preparation for field application as needed from the viewpoints of safety assurance and the actual site applicability.

(2) The first storage facility

As to the first storage facility, during their designing, there are many points of contact with related facilities such as receiving fuel debris and sending samples for analysis, and when they are installed, there are a lot of interfacing and contacts between various types of work and operation including peripheral work. Therefore, project management by TEPCO is essential for process control and resolution of pending issues. Leveraging the experience and knowledge gained from this design and installation work for future projects and construction management is expected. Various remote-control devices are also used for handling fuel debris in the first storage facility. Countermeasures to mitigate potential risks at the design stage should be incorporated into the design, referring to the knowledge of other remote-control devices.

3.1.3.4 Further expansion of the retrieval scale

Toward further expansion of the retrieval scale, TEPCO should take responsibility for examining the methods based on the viewpoint that fuel debris retrieval is an important process in decommissioning, and its retrieval in a reliable manner affects the success/failure of the decommissioning project, and from a comprehensive standpoint including technical feasibility as well as resources and processes. TEPCO has been proceeding with a conceptual study on further expansion of the retrieval scale, starting with Unit 3, and three retrieval methods have been identified as candidates: partial submersion method, partial submersion method option (solidification/fill method), and submersion method. In light of starting further expansion of the retrieval scale in the 2030s, it is appropriate to accelerate the studies. Considering these situations, on narrowing down the directionality of design studies amid high uncertainty, the Japanese government, TEPCO, and NDF needed to cooperate in gathering domestic and overseas technical findings and conducting specialized and focused studies. To that end, since February 2023, the technical feasibility and other aspects were comprehensively studied and evaluated in the Sub-Committee, while placing the utmost priority on safety, and the outcome was summarized in a report on the recommendation for selecting retrieval methods and submitted to the Decommissioning Strategy Committee in March 2024.

When proceeding with examining methods, the Fukushima Daiichi NPS containing the reactors involved in the accident has a unique environment that is substantially different from a conventional reactor, requiring understanding of the following factors that make fuel debris retrieval difficult.

① Extremely high-radiation dose in PCVs and RPVs
② High-radiation dose in reactor buildings
③ Insufficient on-site information
④ Building containment barriers
⑤ Possibility of criticality
⑥ Quantity of waste generated

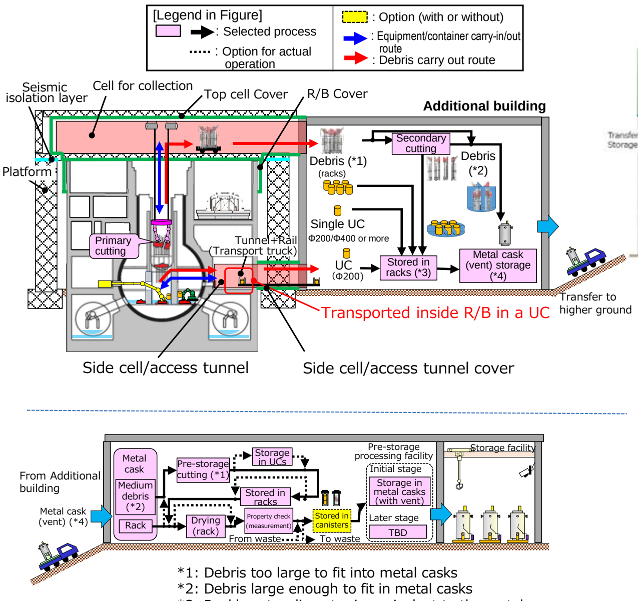
Based on the above factors, the following points should be considered when studying and evaluating retrieval methods.

- Given an unusual environment different from normal reactors, it is important to consider the retrieval method by setting the level of safety to be aimed at in the end with appropriate requirements to achieve it, on the premise that safety assurance is definitely feasible.
- For on-site information such as the location, quantity and properties of fuel debris, a comprehensive analysis and evaluation is conducted to estimate the information necessary for the method study, based on previous internal investigations, analytical evaluations, and past finding. Such efforts should be continued in the future, and the new results obtained should be reflected into information for the method study as appropriate to improve the accuracy of method study.

- It is important to examine scenarios of fuel debris retrieval by each unit and to clarify paths from start to completion in this retrieval method examination. In considering paths to retrieve fuel debris, it is necessary to control potential issues in each process from preparatory work to the completion of fuel debris retrieval, and it is also necessary to develop fuel debris retrieval scenarios while constantly checking the difficulties with the issues and measures.
- The operations, devices and equipment, and facilities will become larger in scale, and the scope of construction will become wider. Therefore, the issue is to perform the examination by overviewing the entire Fukushima Daiichi NPS, including other construction works. For this reason, in addition to the requirements for operations and equipment related to retrieval methods (containment, criticality control, operability, maintainability, throughput, etc.), the requirements for the entire power plant (site use area, interfacing with existing installations, groundwater management, waste management, etc.) should be clarified further.
- As a method to systematically and comprehensively identify issues latent in the developed retrieval method, an effective means is to examine the construction sequence (a series of steps) from preparatory work through fuel debris retrieval, maintenance and completion of fuel debris to exhaustively identify issues that may significantly affect the technical feasibility of each process work. The issues identified should be verified as to whether they can be addressed from the perspective of actual site applicability and technological feasibility while considering countermeasures.
- When evaluating retrieval methods, in addition to evaluation to confirm that they meet the targeted safety level and to check the actual site applicability and technology feasibility based on the Five guiding principles (safe, proven, efficient, prompt, and field-oriented), the evaluations with resources, processes, worker availability and social acceptability, should also be used as decision indexes. Also, information (e.g., exposure assessment reports, structure evaluations) to objectively determine whether the criteria are met should be clarified in advance.

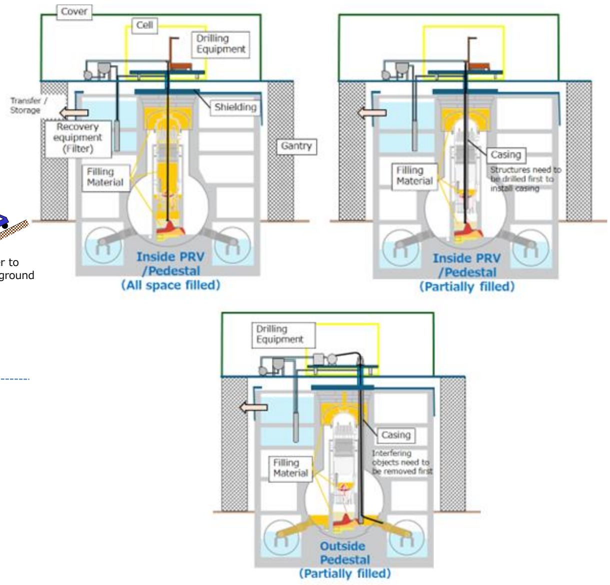
A summary of the report compiled as an outcome of the Sub-Committee is set out below.

The followings are the overviews of partial submersion method (Fig. 6 (a-1)), partial submersion method option (solidification/fill method) (Fig. 6 (a-2)) and submersion method (Fig. 6 (b)), and their advantages and issues as retrieval methods that have been studied conceptually.

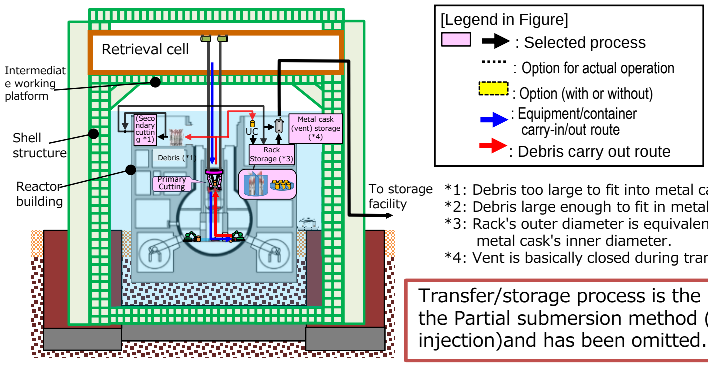


*1: Debris too large to fit into metal casks
*2: Debris large enough to fit in metal casks
*3: Rack's outer diameter is equivalent to the metal cask's inner diameter.
*4: Vent is basically closed during transfer.
*5: Cutting into a size that fits in a dryer or canister

(a-1) Partial submersion method



(a-2) Partial submersion method option (Filling and solidification method)



*1: Debris too large to fit into metal casks
*2: Debris large enough to fit in metal casks
*3: Rack's outer diameter is equivalent to the metal cask's inner diameter.
*4: Vent is basically closed during transfer.

Transfer/storage process is the same as for the Partial submersion method (RPV water injection)and has been omitted.

Fig. 6 An example of each retrieval method for further expansion of the retrieval scale

a -1 Partial submersion method

A method for retrieving fuel debris exposed to the air or immersed at a low water level. The summary of advantages and issues of partial submersion method is shown below.

Advantages	• As it is performed without major change to the state maintained in the air, few concerns are posed over issues associated with change in the state. • Fuel debris retrieval can be started earlier than the submersion method. • It allows selecting fuel debris crushing and collection methods according to the state inside, such as selecting from multiple top-access methods and combining top-access and side-access.
Issues	• As the radiation dose of the work site is high, various remote-control devices will be required compared to other methods. The development, design, and verification of the devices will require a long time, and it is possible that the design of a device will have to be changed after introducing the device at the work site. Considering that rescue of remote-control devices takes a substantial amount of time, studies on the recovery method in a high-radiation dose environment or means to prevent the inside of the cell having a high radiation dose will be required. • As high-radiation dose fuel debris and waste will be taken out from the top, the operating floor will have to have an extremely heavy cell and retrieval devices installed, and a large-scale aseismic working platform to support them will be required.

a -2 Partial submersion method option (solidification/fill method)

A method for retrieving fuel debris and in-core structures by reducing the on-site radiation dose while stabilizing the fuel debris with filler materials, then drilling through a relatively small opening in the operating floor. The summary of advantages and issues of partial submersion method option (solidification/fill method) is shown below.

Advantages	• Fuel debris, etc., inside the RPV and at the bottom of the pedestal can be temporarily stabilized by solidifying with filler materials. In addition, solidifying allows uniform and simple handling during retrieval. • Radiation dose reduction on the operating floor is expected due to the shielding effect of filler material and accessing inside the reactor through a small opening. As a result, the size of the cell to be installed on the operating floor, the cell cover to encase it, and the working platform to support them may be made smaller. In addition, rescue of devices in the event of a failure may be performed through direct operation by workers on the operating floor. • Direct manual operation in the operating floor can be expected for rescue in the event of equipment failure • Excavation devices will be remotely controlled, but their structure will be simple as they will only require moving in one vertical axis basically. In addition, the tip bit, etc., can be replaced according to what to excavate, offering flexibility. • Compared to the partial submersion method and submersion method, the scale of installations can be smaller, and fuel debris retrieval work may be started the earliest.

Issues	• Selection of filler materials (fluidity, curing time adjustability, mechanical properties after solidification, thermal conductivity, chemical stability, deterioration due to radiation, etc.) and establishment of filling method and filling state checking method will be required. • Selection and verification of the tip bit, etc., according to what to excavate will be required. • The amount of waste generated will increase according to the area of filling. In addition, if the substances are to be collected in sludge form, their handling will require attention.

b Submersion method

A method for retrieving fuel debris involves enclosing the entire reactor building with a new structure called shell structure as containment barriers, flooding the reactor building. The summary of advantages and issues of submersion method is shown below.

Advantages	• The radiation dose on the operating floor will be reduced by water shielding, along with that, radioactive dust dispersion may be suppressed. • Sturdy containment barriers (shell structure) enable complete isolation from the outside. • Rescue of remote-control devices in the event of failure can be done manually from the operating floor.
Issues	• Verification of on-site workability in the construction of shell structure on the ground under the building (ground stability against earthquakes during construction, etc.) will be required. • Criticality control, water quality control, and leakage control measures need to be established for a large amount of water held. • The shell structure will be huge. • The preparatory construction period will be the longest, and the fuel debris retrieval work starting time will be the last.

Based on the evaluation of these retrieval methods, the Sub-Committee recommends the following matters to be considered in the selection of a retrieval method.

- It is desirable not to stick to one of the three retrieval methods, but to consider the scenarios in which the strengths of each retrieval method are combined to complement the weaknesses and alternative methods
- It is not advisable to select submersion method as the retrieval method to be totally implemented at this stage. On the other hand, the advantages of handling high-dose materials in water are significant, and it is undeniable that there is a possibility of shifting from partial submersion method to a method that can utilize the function of water shielding in the future.
- Partial submersion method is the basic retrieval method due to large system in scale and complete dependence on remote operated equipment, there are great concerns about overall performance.

- The Partial submersion method Option is expected to be effective in stabilizing the fuel debris temporarily. However, it cannot be denied that technical examinations have not been sufficiently conducted yet. If a certain level of confidence can be obtained for the basic feasibility of this retrieval method, this would enable to improve Partial submersion method further by applying the functionality of filling and solidifications.
- Whichever method will be selected, gaining an understandings of the state inside the reactor will be a prerequisite for its design and safety assurance. It is essential to accelerate internal investigations in the future and concurrently select retrieval methods and study its design.

Comprehensively considering these recommendations, the Sub-Committee recommends that it is appropriate to:

- ✓ start design studies, research and development for a combination of the partial submersion method and the partial submersion method option;
- ✓ proceed with small-scale internal investigations alongside, by accessing from the top; and
- ✓ concurrently study on methods using the shielding function of water as well.

If future internal investigations, etc., find new challenges, retrieval scenarios may be changed even amid a design study, and in some cases the method itself may be retroactively revised.

Sub-Committee proposes the following as the future course of action.

① How to proceed with specific design studies at TEPCO
TEPCO needs to start specific design studies based on the recommendations by the Sub-Committee, and work on issues stated in the reports of internal investigations and research and development at the same time.

② How to proceed with giving shape to safety assurance
The concept of safety assurance, criteria and the rationale shall be determined as early as possible, and they shall be reflected on basic designs and detailed designs taking into account the views of and suggestions from the regulator.

③ Follow up by the Sub-Committee
The Sub-Committee will continue to exist for the time being, and follow up design studies and research and development at TEPCO.

④ Dialog with municipalities and residents in the relevant area
The contents of Sub-Committee reports, implementation status of design studies at TEPCO, etc., shall be fully shared with the municipalities and residents in the relevant area through dialogs.

TEPCO has been working on specific design studies in accordance with the above-mentioned report of the Sub-Committee. The plan is to compile the results by the middle of FY2025, and to move onto the basic design phase. TEPCO established a specific design study implementation plan as the state of its initiatives in and after FY 2024, and submitted it at the Sub-Committee meeting held in July 2024. The content of implementation of specific design studies, schedule of studies and system of studies in the implementation plan are outlined below.

（1） Content of implementation of specific design studies

① Formulation of retrieval scenarios

Based on the recommendations by the Sub-Committee, scenarios of a series of retrieval operations from preparatory work, internal investigation, retrieval, on-site transfer, to storage will be formulated by combining the partial submersion method and the partial submersion with solidification/fill, while keeping in mind the scenario of internal investigation that will proceed concurrently.

② Facility plan

Consideration will be given to systems and facilities that will be required in any of the processes of the retrieval scenarios formulated in ①. Consideration will also be given to buildings and new structures to house and install them in. Results of the considerations will be summarized in the form of conceptual design specifications, scheme drawings, etc., as they serve as design inputs into the basic design.

③ Logistics and layout plans

Consideration will be given to logistics and layout plans conforming to the facility plan considered in ②. Similar to ②, results of the considerations will be summarized in the form of conceptual design specifications, scheme drawings, etc.

④ Processes

Consideration will be given to each individual process and the overall process based on the results of ② and ③.

⑤ Subjects of technological development

For all of the processes in the retrieval scenarios formulated in ①, issues that may greatly affect their technical feasibility will be identified and the subjects of technological development necessary to address the issues will be specified. In addition, development will be started for subjects of high development priority.

⑥ Study of retrieval methods taking advantage of shielding function of water

The data on the ground near reactor buildings including the lower part of the buildings at the time of the construction will be examined to check the feasibility of the shell structure installation.

⑦ Approach to ensuring safety and setting criteria for determination

Consideration will be given to the general safety guides specific to the Fukushima Daiichi NPS, and the safety requirements for fuel debris retrieval will be organized.

（2）　Schedule of studies

Studies on specific designs will proceed with the aim of completing them by the middle of FY 2025. In addition, progress will be reported at a frequency of about once every 6 months, coinciding with follow-up reports to the Sub-Committee.

（3）　System of studies

TEPCO will perform overall management including specification of specific design study items/policies, organization of issues, and schedule/resource management. In addition, TEPCO will establish cooperative systems with relevant institutions such as Decom.Tech for each study item.

3.1.3.5 Continuation of accident analysis activities (clarification of events that occurred at the accident)

Analysis of the accident at the Fukushima Daiichi NPS is conducted not only at TEPCO but also at various relevant organizations. The NRA, in cooperation with TEPCO, is reviewing findings from accident analyses to help investigate the causes of the accident and improve nuclear safety in the future. The Atomic Energy Society of Japan also continues its activities concerning analysis of the accident. With regard to international cooperation, projects on accident analysis are in progress at the OECD/NEA based on the knowledge of various countries and organizations.

As part of accident analysis activities by TEPCO itself, to clarify the events that occurred at the time of the accident, TEPCO identified 52 issues as unconfirmed and unresolved matters regarding the accident at the Fukushima Daiichi Nuclear Power Station and has made reports on the progress of investigations and studies based on the outcome of internal investigations and other findings. The results of 38 studies, including all 10 classified as high-priority issues, are reported by the 6th progress report in November 2022. TEPCO has been conducting estimations of the state of the RPV and PCV referring to these accident analysis results and is reflecting the results on the systematic implementation of on-site investigations and the examination of fuel debris retrieval method and storage/management. Meanwhile, studies are not progressing well on the remaining 14 issues, including reaction between molten core components and concrete and release of radioactive materials from PCVs during venting. Going forward, internal investigations to be conducted in the course of the trial retrieval in Unit 2 and analysis of retrieved fuel debris are expected to provide information useful for such accident analysis activities.

3.1.3.6 Progress of research and development for further expansion of the retrieval scale

For issues that are difficult to address in engineering or far-sighted issues, the “Project of Decommissioning, Contaminated Water and Treated Water Management” (hereinafter referred to as the “subsidized project for decommissioning”) has been promoting research and development. This R&D is being carried out in accordance with the R&D medium-and-long-term plan and the next-term R&D plan that are described in Chapter 5.2, and it is important to proceed exhaustively, systematically and efficiently while confirming that it is in line with the needs of TEPCO as the entity responsible for decommissioning. The following is a list of research and development items being performed. Note that, they are research and development common for each method, except for (7). Although (7) is research and development relating to the partial submersion method only at present, those for other methods will be initiated by identifying research issues as necessary in the future.

(1) Technology for RPV internal investigation
(2) Technology for work environmental improvement inside the reactor buildings
(3) Development of analytical technology for radiation exposure dose assessment
(4) Liquid treatment system (α-emitting nuclide removal technology)
(5) Technologies for containment, transfer and storage of fuel debris
(6) Data acquisition of dust dispersion rate
(7) Fuel debris retrieval method

3.1.3.7 Issues in examining safeguards strategies

Since material accountancy and safeguards for the retrieved fuel debris are unprecedented, TEPCO may face technical issues in examining and applying them to the site. For this reason, NDF will conduct wide-ranging surveys on existing technologies related to material accountancy and safeguards to prepare in case that TEPCO needs technical assistance. NDF will also check the progress of the project from an engineering perspective to confirm that the application of safeguards to installations does not affect the decommissioning process.

3.2 Waste management

3.2.1 Target

- The Solid Waste Storage Management Plan (hereinafter referred to as the "Storage Management Plan") is developed and revised with updating the estimated amount of solid waste to be generated in the next 10 years, as well as appropriate storage/management should be implemented including waste prevention, volume reduction, and monitoring of storage/management conditions based on it.
- Develop and update the analysis plan necessary to advance the consideration of storage/management, processing, recycling and disposal, and proceed steadily with analysis based on it.
- Based on the prospects of processing/disposal method of solid waste and technology related to its safety (hereinafter referred to as "Technical Prospects") presented in FY 2021, the creation of options for storage/management, processing, recycling and disposal measures and their comparison and evaluation should be conducted with promoting characterization. Studies on detailed waste management processes of the whole solid waste (management from generation to recycling and disposal of solid waste) proceed for presenting appropriate measures. For that, first evaluate the flow of integrated measures for individual solid waste from characterization to recycling and disposal (hereinafter referred to as "individual waste stream") in the overall solid waste management, and accumulate the individual waste stream option proposals that have been recognized as safe and feasible. Then, integrate all individual waste stream option proposals together and form entire waste stream (hereinafter referred to as "waste stream").

3.2.2 Progress

- Since a large amount of solid waste with various characteristics is generated in association with decommissioning, the efforts based on the following "Basic Policies on Solid Waste" are underway.
- In the Storage Management plan published in November 2023, a considerable amount of waste (at least about 300,000 m^3) is expected to be generated in the preparatory works for fuel debris retrieval. This amount of waste generated is estimated based on the assumption of uncertainty due to the fact that the fuel debris retrieval method has not been determined for the dismantling of the buildings around Units 1 to 4 and the resin generated before the earthquake. In the future, the amount of waste generated will be scrutinized in anticipation of the volume reduction effects of incineration, crushing, etc.

< Basic Policies on Solid Waste>

(1) Thorough containment and isolation	(5) Establishment of selection system of preceding processing methods in consideration of disposal
(2) Reduction of solid waste volume	(6) Promotion of effective R&D with an overview of overall solid waste management
(3) Promotion of characterization	(7) Development of continuous operational framework
(4) Thorough storage/management	(8) Measures to reduce radiation exposure of workers

3.2.3 Key issues and technical strategies

In Phase 3, in order to determine the specifications of waste form and their production methods, institutions concerned, led by NDF, are promoting technical studies on integrated measures from characterization to storage/management, processing, recycling and disposal of solid waste, based on their respective roles. The status of each area is shown below.

3.2.3.1 Characterization

While accumulating analytical data, inventory for solid waste will be continuously improved, which is the basic information for solid waste management, including processing/disposal. Although the analysis work itself is not difficult, low-activity waste has the feature of enormous volume. And the limited number of analyses data obtained for high-activity waste due to the difficulty of sampling. Considering their features, analysis of such waste makes it important to take an approach that ensures the required accuracy efficiently. For these issues, efforts are being made to establish an efficient analysis evaluation method.

Capacity of analysis has been enhanced with the completion of the Japan Atomic Energy Agency (hereinafter referred to as “JAEA”)'s Radioactive Material Analysis and Research Facility Laboratory-1 on site of the Fukushima Daiichi NPS in June 2022. With that capacity in mind, analyses contributing to solving issues in the decommissioning process will be performed systematically, considering the priority of samples. Using acquired data for overall waste management, TEPCO should provide comprehensive management of solid waste characterization, including adjustment of the entire process of collecting samples for analysis, securing facilities for analysis, transporting samples, etc. (hereinafter referred to as “analysis supply chain”).

TEPCO developed an analysis plan for the characterization and optimization of storage/management to discuss solid waste processing/disposal methods and recycling measures in March 2023, and updated it in March 2024. Based on this plan, TEPCO and the JAEA will work together to incorporate into detailed analysis work, review the analysis plan, identify the details of necessary technical development tasks, and establish the operational structure of the analysis supply chain early.

3.2.3.2 Storage/management

Storage/management of solid waste should be appropriately implemented depending on the risk, such as radioactivity concentration and properties, etc. Moreover, it is important to reconsider measurement items and timing, etc., while acquiring necessary information through continuous monitoring of the storage/management status. Though the current storage/management of solid waste is based on the classification by surface radiation dose rate, in preparation for the expected increase in the amount of solid waste generated, it will transit to the management by concentration of radioactivity and examine the rational classification of waste and recycling on-site based on these.

Measures for Mid-term Risk Reduction at TEPCO's Fukushima Daiichi NPS indicate that the goal regarding the development of a method for managing radioactivity concentration of rubbles based on surface dose rate is FY 2025 for low radiation dose/BG-equivalent rubble, and FY 2028 for medium-dose rubble. To this end, data on nuclide concentration ratios with Cs-137 being the key nuclide will be accumulated and evaluated, and examinations will be advanced on the revision of the group, taking into account the similarity in the trend of contamination and the acquisition of additional analysis data, as necessary, while providing feedback to the analysis plan.

The solid waste, etc., from dismantling buildings that is expected to be generated in large quantities in the future has been classified and managed by the surface radiation dose after generation of the waste, and radioactivity concentration has not been managed to date. In the future, the state of facility concentration is grasped in advance by nuclide analysis, and their processing will be transitioned to a method to perform decontamination, dismantling, and storage/management of dismantling waste according to the concentration, leading to rational processing/disposal. The first key is to consider dismantling model cases targeting specific facilities, in order to apply the method to future facility dismantling efforts and measures for addressing generated dismantling waste.

The Mid-and-Long-term Roadmap calls for eliminating temporary outdoor storage of all solid waste, excluding secondary waste generated by water treatment and waste subject to recycling and reuse, by the end of FY 2028. To achieve this goal, it is necessary to develop necessary facilities and installations systematically including incineration/volume reduction facilities and solid waste storage, and promote steadily consolidate storage of solid waste inside buildings. In addition, taking into account the views of the Committee on Oversight and Evaluation of Specified Nuclear Facilities and the Technical Meeting on the Examination of the Implementation Plan of the Measures for the Specified Reactor Facilities, regarding the practicality and rationality of storage of low-level concrete and other waste, it is important to examine storage/management methods which are safe, reasonable and feasible.

The storage capacity of ALPS slurry has been secured for the time being through the expansion of storage facilities. Because the upper limit of the integrated absorbed dose (5,000 kGy) will be evaluated to exceed before the commencement of the stabilization process, stabilization/treatment system installation and processing will proceed in a planned manner, as well as securing the immediate storage capacity for HICs that needed to be transferred, and its transfer will be ensured.

Issues and measures for storing/managing high-activity waste to be generated by further expansion of the retrieval scale, which were clarified by fiscal 2021, will be reviewed along with examining the fuel debris retrieval methods. In preparatory works for the retrieval of fuel debris, it is expected that a large amount of concrete and metal with low radioactivity concentrations will be generated due to the demolition of buildings, etc. Therefore, it is essential to continue the current measures for reducing the volume of materials and to conduct a study on the possibility of further reduction.

3.2.3.3 Processing/disposal

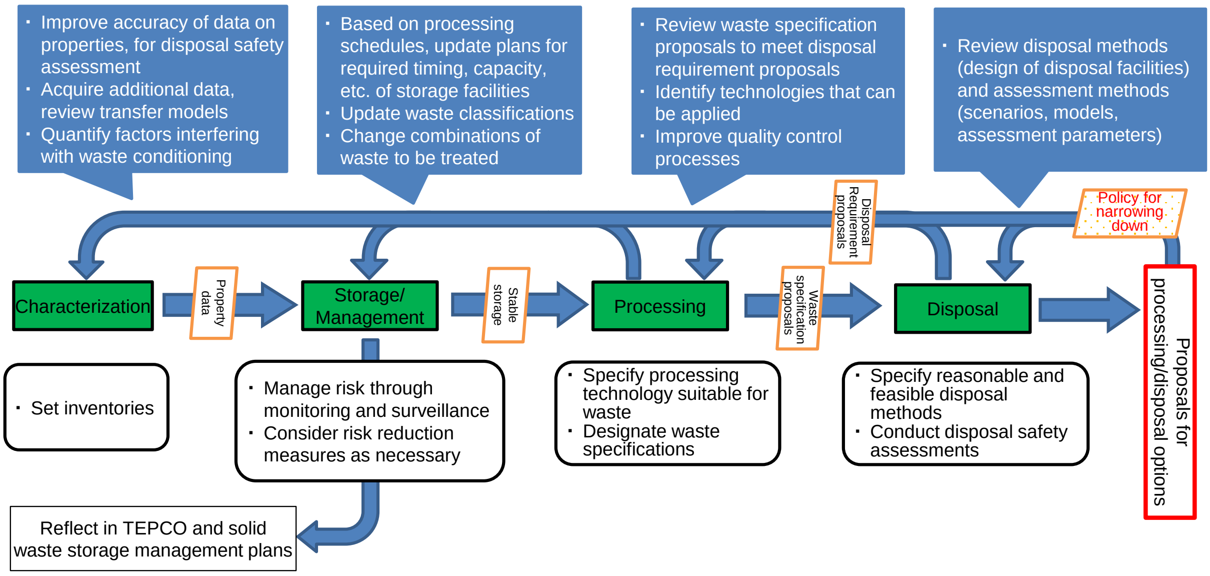
Findings will be widely acquired by mutually feeding back research results in each field on individual waste streams, and the characteristics of draft individual waste stream options with recognized safety and feasibility will be evaluated and the results will be accumulated. The draft individual waste stream options will be integrated, and then, evaluated and examined the results, and narrowed down to establish an appropriate waste stream.

The R&D of processing and disposal technologies required for the series of studies, as shown in Fig.7, will be continued.

Regarding the processing technologies, pending issues in normal-temperature and thermal processing technology, for which research/development is promoted, will continue to be addressed. Securing storage capacity is an issue for ALPS slurry constantly generated from water treatment. Thus, in light of the point at issue regarding the dehydrate technologies for ALPS slurry in the Study Group on Monitoring and Assessment of Specified Nuclear Facilities and the Technical Meeting on the Examination of the Implementation Plan of the Measures for the Specified Reactor Facilities, requirements for selecting treatment technologies to be applied will be discussed with priority. As a matter of immediate consideration, a study will be conducted on the possibility of a technology for solidifying a large amount of rubble, which is difficult to separate, in a batch without segregating it, and on a technology for integrated treatment of slurry dehydrates and their containers.

Concerning disposal technology, considering the characteristics of radioactive waste, key scenarios that may affect the feasibility of disposal will be identified based on studies on the long-term evolution behavior, etc., of the disposal facilities, needs for the disposal concept will be ascertained based on the key scenarios, etc., and a draft disposal concept option will be established and improved as a measure to address the needs by employing available resources, such as safety assessment technology that has been advanced and knowledge in Japan and overseas, as appropriate. Furthermore, after expanding the target of individual waste streams incorporating this draft disposal concept option, a draft disposal concept option covering all radioactive waste at the Fukushima Daiichi NPS will be considered. Then, contributions will be made to considering appropriate detailed waste management approaches as a whole in coordination with knowledge gained in areas of waste management other than disposal.

■ Procedure to reasonably select safe processing/disposal methods of solid waste



■ Input of research results and feedback of issues in each field in waste stream studies

Measures and studies based on the current situation (Research results to be input to downstream)

Characterization	Characterization→Storage/Management	Characterization→Processing	Characterization→Disposal
Characterization←Storage/Management	**Storage/ Management**	Storage/Management→Processing	Storage/Management→Disposal
Characterization←Processing	Storage/Management←Processing	**Processing**	Processing→Disposal
Characterization←Disposal	Storage/Management←Disposal	Processing←Disposal	**Disposal**

Current issues (issues to be fed back to upstream)

Fig.7 Procedure to reasonably select safe processing/disposal methods of solid waste

3.3 Contaminated water and treated water management

3.3.1 Target

- Under the three principles concerning the contaminated water issues ("removing" contamination sources, "redirecting" fresh water from contamination sources, and "retaining" contaminated water from leakage), the target is to control the amount of contaminated water generated to about 50 to 70 m^3/day by the end of FY 2028 with the average rainfall, while continuing the operation of the constructed water-level management system. Moreover, to ensure the stable implementation of contaminated water management, measures for mitigating large-scale natural disaster risks, such as tsunamis and storm rainfall, will be implemented in a planned manner.
- To arrange the relationship with a decommissioning process including full-scale fuel debris retrieval beginning in the near future, and to promote examination of the measures of the contaminated water management for medium-and-long term prospects.
- To discharge ALPS-treated water safely and reliably to secure the site and other resources and steadily advance the entire decommissioning process.

3.3.2 Progress

- Through multilayered contaminated water management such as land-side impermeable walls and sub-drains along with the prevention of rainwater infiltration by repairing damaged building roofs and facings on site, even if FY2023 saw rainfall-adjusted contaminated water generation of approximately 90 m^3/day (adjusted to an average rainfall-equivalent level because the annual rainfall was approximately 200 mm less than the approximately 1,470 mm average year level), achieving the Mid-and-Long-term Roadmap's goal of "approximately 100 m^3/day or less by the end of 2025" two years ahead of time.
- In FY 2022, a milestone in the Mid-and-Long-term Roadmap was achieved: "to reduce the stagnant water in reactor buildings in FY 2022 to 2024 to about half of the level at the end of 2020". To achieve water level reduction toward exposure of the floor surface of the process main building (hereinafter referred to as "PMB") and the high-temperature incinerator building (hereinafter referred to as "HTI"), preparations are currently being made for the recovery of zeolite sandbags with high-radiation doses placed on the basement floors and for the installation of temporary storage facilities for stagnant water instead of storage on the basement floor.
- As a measure to reduce risk associated with tsunamis, construction of the Japan Trench tsunami tide walls was completed in March 2024. As for a measure against heavy rain, the Drainage Channel D has been in service since August 2022 to eliminate the risk of inundation in the vicinity of Units 1 to 4, and the drainage function of the existing drainage channels has been enhanced systematically.

- Since the first discharge of ALPS-treated water into the sea in August 2023, discharge has been performed eight times in total in about 1 year. The total amount of ALPS-treated water discharged to date was about 63,000 m^3, and the amount of tritium discharged was about 10 trillion Bq. During the period of treated water discharge, rapid analyses of tritium concentration in the seawater were performed at 14 locations near the NPS. After the eight times of discharge performed to date, the concentration has been below the detection limit or 1/10 or less than the operation target (level to judge suspension of discharge or level to initiate investigation) at all locations, indicating that the discharge into the sea has been performed safely according to plan.

3.3.3 Key issues and technical strategies

3.3.3.1 Control of contaminated water generation amount

As for the amount of contaminated water generated, the Mid-and-Long-term Roadmap target “about 100 m^3/day or less by 2025” was achieved. However, maintenance of sub-drains and land-side impermeable walls will be continued to steadily control groundwater around the buildings at low levels, and facing (ground surface paving) inside the land-side impermeable walls and repair of damaged building roofs will be promoted as measures to prevent infiltration of rainwater. In addition, as local water sealing around the Units 1 to 4 buildings, water sealing will be applied to the deep building outer water penetrations and gaps between buildings to achieve the target “reduce the amount of contaminated water generated to about 50-70 m^3/day (end of FY 2028)”.

At 2.5 meters above sea level, there still remains the contamination that leaked from the buildings via the seawater pipe trenches (an underground structure made of reinforced concrete that houses pipes for intake of seawater) immediately after the accident, and groundwater is pumped up by well point method (hereinafter referred to as “WP”) to prevent the release of the contaminated water. From a viewpoint of reduction of the amount of contaminated water generated, as a medium - to long-term measure, first and foremost, it is necessary to steadily implement measures to prevent the water from leaking into the building and to demonstrate the effects of these measures. Based on the results of future surveys and examinations, considerations need to be made on WP pump-up amount reduction measures, including those to address contaminated soil at 2.5 meters above sea level.

3.3.3.2 Treatment of stagnant water in buildings

(1) Further reduction of stagnant water

Due to the presence of high-radiation dose sludge containing cesium and α-nuclides near the floor of the reactor building, lowering the water level of the building too much may lead to reduced water shielding effect and deterioration of the working environment.。 Moreover, if contaminated water with a radioactivity concentration several orders of magnitude higher than usual flows into the cesium sorption apparatus, the purification performance may be significantly degraded. Although reducing the amount of stagnant water in the reactor building to about half the level (about 3,000 m^3) at the end of 2020 has been achieved, further reduction requires consideration of integration with the fuel debris retrieval method. For example, even in the case of partial submersion method, the target for reducing the amount of stagnant water in the buildings differs depending on whether the inside of the building is to be dried up or the stagnant water is to be circulated and poured. Therefore, it is important to specify the ideal way of the stagnant water management in conjunction with the examination of the retrieval methods for further expansion of the retrieval scale for fuel debris.

(2) Stagnant water treatment in the process main building and high-temperature incinerator building

At present, stagnant water in the building is also stored on the basement floors of the process main building (PMB) and the high-temperature incinerator building (HTI) building, and the actions below will be taken as measures to reduce the water level toward the exposure of the floor surface.

- Recovery of zeolite sandbags with high-radiation doses placed on the basement floors of the PMB and HTI

Since zeolite sandbags have high-radiation doses, the planned procedure is to collect them in a submerged environment using a robot for collecting, transfer them to the aboveground floors using a robot for sealing in containers, seal them into storage containers after dehydrating in the building, and transfer them to temporary storage facilities. Collection work will be highly challenging as it requires collecting high-radiation dose objects on underground floors with narrow passages through remote operation. Therefore, it needs to carefully proceed in steps, while making improvements based on knowledge obtained by mock-up tests. A full-scale mock-up test found a reduction in the visibility due to sludge being disturbed and turbidity, and the plan is to reflect the findings in the actual collection work.

- Installation of temporary storage facilities for stagnant water instead of storage on the basement floor of PMB and HTI

Toward the exposure of the floor surface of the PMB and HTI, temporary storage facilities for stagnant water consisting of two tanks, a receiving tank and a temporary storage tank are being designed and manufactured to take over the function of a buffer tank that has been performed by the PMB and HTI. As the temporary storage facilities for stagnant water will be significantly smaller in scale than before, it is designed to have a two-tank configuration of a receiving tank and temporary storage tank and manufactured to be able to maintain the function even with a small capacity, and its operation check, etc., is planned to be performed from FY 2025. Sludge separated and collected in the receiving tank is discharged to a limited area in the underground floor of the PMB for the time being. The water is collected through a floor funnel (drain outlet on the floor) to a temporary storage facility for stagnant water, so that only drained sludge is planned to be stored. Equipment to directly collect sludge from the receiving tank is installed in the future to eliminate sludge storage in the PMB basement floor and further reduce risks.

3.3.3.3 Issues of contaminated water management considering the decommissioning process such as fuel debris retrieval

(1) Examination of water treatment systems for dispersion prevention of α-nuclides and fuel debris retrieval

Analysis of stagnant water in buildings to date found that α-nuclides exist mainly in the form of granular particles, a total alpha concentration below 10 Bq/L is currently maintained at the cesium sorption apparatus (SARRY/SARRY II) outlet, and the spread of contamination by α-nuclides to the downstream side is suppressed. In the future, with the increase in the accumulated sludge at the bottom of the building due to fuel debris retrieval work, more sludge may be mixed into the contaminated water, and the total alpha concentration at the water treatment system inlet may rise. To address such concerns, installing filtering systems (α-nuclides removal equipment) in the subsequent stage of the cesium sorption apparatus is under consideration.

During fuel debris retrieval, contaminated water containing a large amount of fine particles is generated by crushing, including cutting and other processes, and α-nuclides in fuel debris may exist in various forms, such as fine particles, ions, and colloids. While the water quality of such contaminated water depends on the crushing method, including cutting and other processing, it is difficult to assume the water quality when the fuel debris retrieval method has not been determined. Thus, the water treatment system for fuel debris retrieval should be designed considering foreseeable variations in the water quality and the resultant forms of α-nuclides.

(2) Medium-and-long term measures for contaminated water management systems

To maintain the effectiveness of contaminated water management over the medium-to-long term, it is necessary to implement periodical inspection and updating of facilities including the land-side impermeable wall, sub-drain systems and existing water treatment systems (e.g., SARRY, ALPS) without fail. To this end, it is important to assume various risks such as aging, strengthen the system for monitoring and early recovery measures, arrange procurement of spare and replacement parts for stable operation, and proceed with maintenance and facility renewal in a planned manner.

In addition, since it will take a long time to complete fuel debris retrieval, establishing an approach to more stable measures for contaminated water and more appropriate maintenance/management of each facility should be considered by taking a broad view of contaminated water management in the medium to long term, in conjunction with the selection of methods for further expansion of the retrieval scale that is currently underway. It is desirable to employ a contaminated water management method that also allows in-leak control on the assumption of preventing the out-leak of contaminated water, including the continued operation of the current groundwater inflow limitation measures. Thus, measures including the installation of structures for fuel debris retrieval and contaminated water management during the dismantling of surrounding facilities will be required. For the medium-to-long term contaminated water management, studies should be promoted in accordance with the progress of the whole decommissioning process including fuel debris retrieval methods, together with the confirmation of actual site applicability and technical feasibility.

3.3.3.4 Future efforts for the discharge of ALPS-treated water into the sea

Based on the Action Plan for Steady Implementation of the Basic Policy on the Disposal of ALPS Treated Water formulated by the government, it is essential for TEPCO to reliably operate the installations in accordance with its own plan for the discharge of ALPS-treated water into the sea and continue to timely communicate the status with high transparency.

Considering that treatment of high tritium concentration water in the Primary Containment Vessel is planned for the future, TEPCO will have to formulate processing, transfer, and storage plans for tanks. In addition, some ALPS-treated water will have to be transferred for a long distance using a temporary line from storage tanks away from facilities for measurement and checking in the future. Therefore, it is important to strengthen leakage countermeasures such as double use of temporary hoses and installation of leakage detectors, as well as to convert temporary sections into main facilities.

Upon formulation of a discharge plan, it is necessary to develop a plan in accordance with a site use plan, while considering the concentration and decay of tritium contained in treated water in tanks. It is important to consider, draft, and publish a medium-and-long-term discharge plan and a site use plan, so that facilities and installations necessary for the decommissioning work including fuel debris retrieval and removal of fuel in SFP can be constructed systematically.

Regarding analysis of ALPS-treated water, in addition to the nuclides to be measured and evaluated (30 nuclides excluding tritium), TEPCO, KAKEN, and JAEA have performed analyses/evaluations and disclosed the results regarding (38) nuclides for which TEPCO has voluntarily confirmed their lack of significant presence. These nuclides need to be periodically reevaluated for their changes resulting from the decay of the radioactive materials and measurement results, and have examinations on the need of analyses/evaluations continued, as well as it is also important to seek public understanding for the reduction of the target nuclides through easy-to-understand explanations based on scientific grounds.

3.4 Fuel removal from spent fuel pools

3.4.1 Target

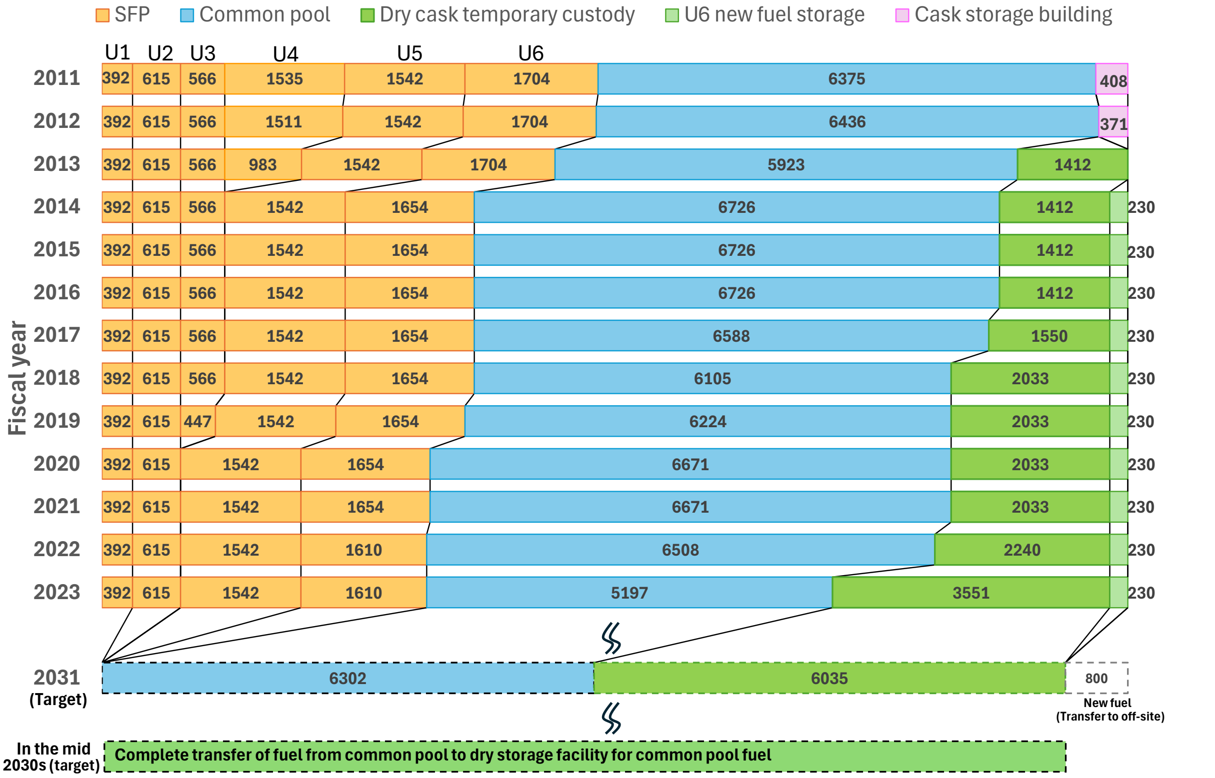
- To complete fuel removal from the spent fuel pools of all Units from 1 to 6 by the end of 2031.
- As the return of residents and reconstruction in the surrounding area gradually advances, to carry out a risk assessment and ensure safety, including preventing the dispersion of radioactive materials, and to start removal of fuel in SFPs in FY 2027 to FY 2028 for Unit 1 and FY 2024 to FY 2026 for Unit 2.
- The fuel in Units 1 to 4, which were affected by seawater and rubble, is retrieved from the SFPs and transferred to the Common Spent Fuel Storage Pool, etc., where it is appropriately stored to be in a stable management state. In order to secure the Common Spent Fuel Storage Pool capacity, the fuel stored there is transferred to and stored in the dry cask at the Temporary Cask Custody Area
- To perform the evaluation of long-term integrity and the examination for treatment for the retrieved fuel and to decide the future treatment and storage method.

3.4.2 Progress

Unit 1 :
• The preparatory work was delayed due to delays in the standby gas treatment system pipe removal work. Also, after that, places with a high radiation dose were found on the wall at the south side of the reactor building, which necessitated additional decontamination, shielding work and increased workdays, and large cover installation work is taking time. At the Unit 1 reactor building, installation of the large cover girders is underway. Based on these, the Mid-and-Long-term Decommissioning Action Plan 2024 states that the large cover installation work is to be completed by around the summer of 2025, but Unit 1 fuel removal is still planned to be stated in FY 2027-2028.
Unit 2 :
• At the south side of the reactor building, installation of the fuel removal working platform and front chamber was completed in June 2024, and access routes are currently being established. Production of the fuel handling equipment has also been completed, and its function test is being carried out at the factory. In addition, within the operating floor, decontamination and shielding work was completed in April 2024 after removal of obstacles from the spent fuel handling equipment operation room located on the south side of the spent fuel pool, and with that a series of work toward radiation dose reduction has been all completed. Fuel removal is expected to start in FY 2025. Also, regarding the fuel removal, for the purpose of prompt response to equipment problems, TEPCO employees are to be stationed at the factory in order to master the operation and functions of the boom-type fuel handling equipment that will be the first in Japan.
Unit 3 :
• After starting high-radiation dose equipment removal from the spent fuel pool in March 2023, multiple problems occurred in the fuel handling equipment. After that, the problems were addressed and the operation was resumed in March 2024.
Unit 6 :
• Transfer of Unit 6 spent fuel to be transferred using a dry cask and its storage were all completed in February 2024, securing the available capacity of the Common Spent Fuel

Storage Pool. Therefore, transfer of spent fuel from the Unit 6 spent fuel pool to the Common Spent Fuel Storage Pool is planned to be resumed in May 2024 and completed in the first half of year 2025.

Fig. 8 shows the change in the storage status of fuel since immediate after the accident.



* Dry cask at the temporary cask custody area: Started operation in 2013 Unit 4: Removal from spent fuel pool completed in 2014 Unit 3: Removal from spent fuel pool completed in 2021

Cask storage building (Cask storage building located beside the shallow draft quay before the accident): Stored dry casks were transferred to the Dry cask at the temporary cask custody area in FY 2013. New fuel as of 2031 (800 units) will be transported out of the site. 95 casks will be stored in the Dry cask at the temporary cask custody area.

Fig. 8 Number of fuel of Fukushima Daiichi NPS at the end of each fiscal year

3.4.3 Key issues and technical strategies

3.4.3.1 Fuel removal from spent fuel pools

For Units 1 and 2, it is necessary to advance the work steadily to realize the new retrieval method that has been determined.

In promoting the project, it is essential to evaluate safety in association with work, to confirm that necessary and sufficient safety is ensured, and then to comprehensively consider the technical reliability, rationality, the promptness of the work schedule, the actual site applicability, the project risk, etc., in order to address issues.

(1) Unit 1

Since the overhead crane is present in the upper part of the operating floor in an unstable condition, one of the main issues is to remove the overhead crane in a safe and reliable way. Therefore, in the ongoing examination of how to remove the overhead crane, it is assumed that safety assessments will be performed, and it is important to carry out a comprehensive examination in light of rationality and impact on other operations by:

- Formulating specific work procedures and work plans enabling identification of risk items
- Anticipated risk scenarios and countermeasures
- Identifying points to consider, such as exposure of workers, from the operator's perspective

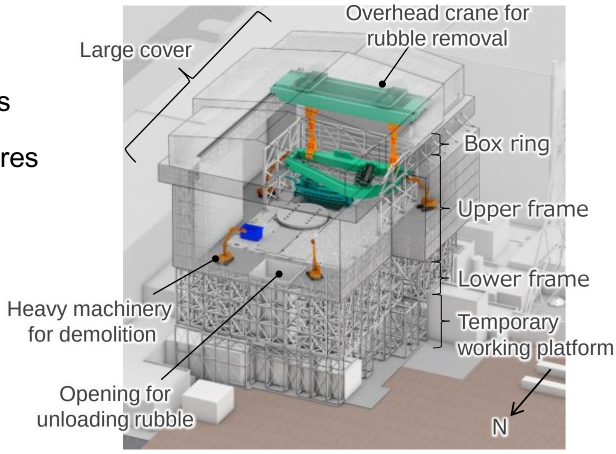


Fig. 9 Overview of the rubble removal from Unit 1 operating floor

The information on the condition of the lower part of the roof slab is limited at present, requiring a detailed investigation after the removal of the slab. Since there is a risk that the crane dismantling process may be delayed depending on the investigation results, investigation should be carried out promptly once it becomes possible, and the results should be incorporated into the safety assessments and rubble removal plans. (Fig. 9)

Regarding the contamination state of the well-plugs of Units 1 to 3, it has been pointed out that the well-plugs have important implications for safety and decommissioning work due to the high level of their contamination. Although the contamination level of the well-plug of Unit 1 is lower than that of Units 2 and 3, it is unstable due to the impact of the accident, and examination is being made on measures to deal with the situation. From now on, a comprehensive decision on how to deal with well-plug should be made based on these examination results and by taking into consideration the impact on fuel removal from SFPs and fuel debris retrieval and performing thorough safety assessments.

A detailed handling plan for 67 fuel assemblies with damaged cladding tubes, which have been stored in the Unit 1 SFP since before the accident, is under development toward the completion of fuel removal in 2031. In particular, efforts should be made to ensure verification of the post-accident condition and risk study associated with handling.

(2) Unit 2

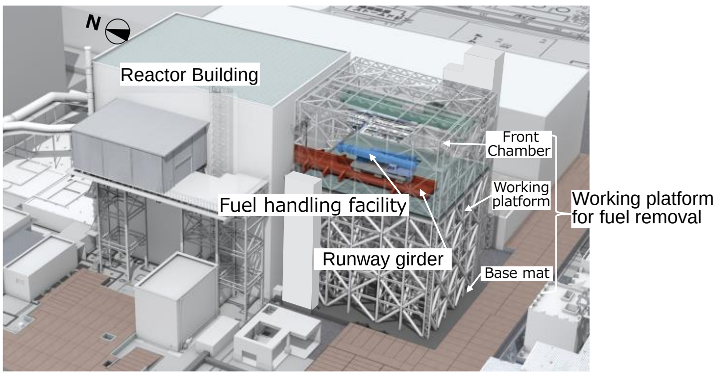


Fig. 10 Fuel removal method in Unit 2 SFP

Fuel in FSP will be removed from the opening on the south side of the operating floor using a fuel handling machine composed of a boom-type crane-system that has never been used at nuclear facilities in Japan before (Fig. 10). Since this is a new installation, the following measures should be taken without fail.

- Function test and verification of operation procedure by actual workers

- Feedback to operation procedure and modification of the installation, as necessary, based on the results of the test and verification

Alongside, persons related to the fuel handling work should master the operation procedure while fully understanding the functions of the installation.

(3) Removing high-radiation dose equipment

Removal of high-radiation dose equipment is ongoing in light of risk reduction in the event of pool water leakage. It is also possible to exclude pool water from management by draining the pool water after removing the high-radiation dose equipment, leading to smooth implementation of subsequent fuel debris retrieval operation because of the increased flexibility of use of the operating floor.

It is effective for removing high-radiation dose equipment to utilize the devices used for fuel and rubble removal. The fuel removal system for Unit 1, which will be installed in the future, should also be designed and maintained in anticipation of the removal of high-radiation dose equipment. Moreover, because the capacity of existing site bunkers for storing high-radiation dose equipment is limited, studies are being made on the construction of new site bunkers. However, since the possibility of pool water in the existing site bunkers leaking until new site bunkers are installed cannot be ruled out, it is important to enhance monitoring and formulate measures against leakage.

3.4.3.2 Decision on future treatment and storage methods

The future treatment and storage methods for fuel in SFPs needs to be decided after considering the impact of seawater and rubble at the accident and the damaged fuel stored since before the accident. Future treatment and storage methods should be determined in light of the condition of the fuel to be removed while examining the long-term integrity assessment and treatment.

TEPCO plans to transfer fuel in SFPs of all Units to the Common Spent Fuel Storage Pool by the end of 2031. Subsequently, taking into account the tsunami risk, the possibility of dry storage on higher ground has been studied, including existing fuel in the Common Spent Fuel Storage Pool. As dry storage facilities, in addition to the existing metal casks, TEPCO is proceeding with preparations in anticipation of introducing concrete casks using canisters that have proven track records overseas and offer the possible advantages stated below (cylindrical metal containers).

- Many overseas track records of storing intact or damaged fuel
- Use of local companies for concrete production
- Reduction in the amount of waste after use with fewer metal parts
- Reduction of procurement risk by expanding options for dry storage facilities

The dry storage facilities to be applied, including storage of damaged fuel, should be determined based on the advantages and disadvantages of both the casks and the characteristics of the Fukushima Daiichi NPS.

In the US, dry storage using concrete casks is the mainstream. Over 3,300 containers (about 143,000 fuel assemblies) have already been stored using concrete casks. When selecting a storage method, the viewpoints of aseismic performance and site boundary radiation dose also need to be considered, in addition to securement of its technical feasibility.

4. Analysis strategy for promoting decommissioning

4.1 Overview of analysis on decommissioning

4.1.1 Purpose and significance of analysis on decommissioning

In the decommissioning of the Fukushima Daiichi NPS, only a few records exist, such as for temperature, and there are many uncertainties regarding the status inside the reactors, the condition of fuel debris, the release path of fission products, and so on. Therefore, the analysis is being conducted for the purpose of handling fuel debris and solid waste generated by the accident safely and appropriately storing/managing them.

If the properties of fuel debris can be ascertained by analysis, an otherwise excessive safety margin in decommissioning work may be optimized by reducing the uncertainty range, and the rapidity and rationality of decommissioning can be improved. In addition, when considering the processing/disposal method for solid waste, the property data such as nuclide composition and radioactivity concentration obtained by analysis will serve as basic information. Since ALPS-treated water is assumed to be released into the environment, it should be confirmed that it is sufficiently below the release standard value by analysis. TEPCO and JAEA have analyzed the ALPS-treated water before and after dilution prior to discharging, and confirmed that it was below the release standard. According to TEPCO's marine monitoring, the concentration was 0.43 to 29 Bq/L at a point close to the discharge port, and below the detection limit at other points. Furthermore, after the discharge started, the Ministry of the Environment, and Fukushima Prefecture conducted analyses of seawater, and the Fisheries Agency conducted analyses of marine products, confirming that the concentration levels were similar to those of seawater before the release (0.06 to 0.63Bq/L), or that below the detection limits in all cases.

4.1.2 Full picture of the analysis

In the decommissioning work of the Fukushima Daiichi Nuclear Power Station, analyses covering a wide range of analysis targets, purposes, and dose rates must be performed as shown in Fig. 11.

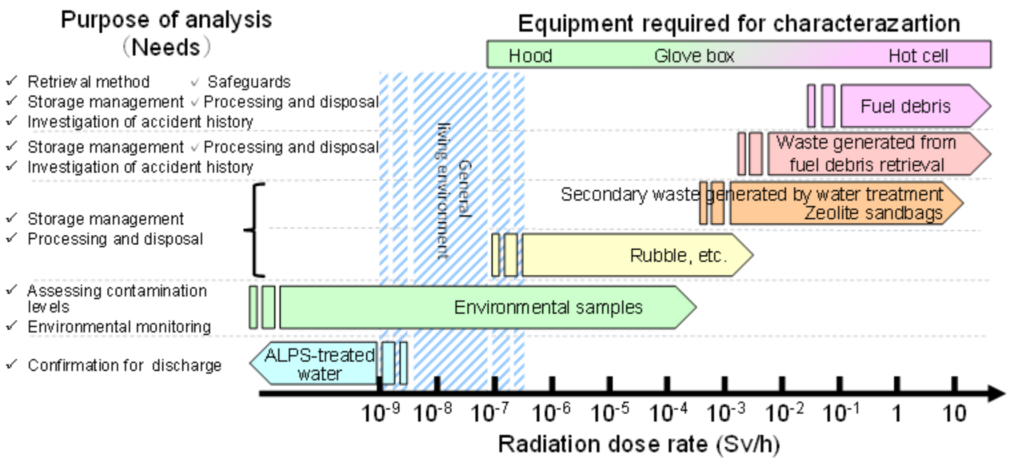


Fig. 11 Relationship between the purpose of the analysis, equipment required for characterization, and radiation dose rates of the analysis targets

Adequate results obtained from these analyses are indispensable for achieving these conditions and for the safe and steady progress of decommissioning work at the Fukushima Daiichi NPS. In order to obtain the appropriate analysis results, it is effective to improve the three elements of the analysis strategy in decommissioning (Method and system of analysis, quality of analysis results, size and quantity of samples).

4.2 Current status and strategies for analysis

4.2.1 Measures to strengthen analytical structure and analysis method

(1) Measures to strengthen analysis structure

To strengthen the analysis structure necessary for decommissioning the Fukushima Daiichi NPS, while TEPCO, the JAEA, NDF, and other related organizations have been working together by studying analysis plans, developing radiological analysis/evaluation methods, securing facilities for analysis, and recruiting analysis personnel, the immediate measures for the development of these analysis structure are announced and reported. Our initiatives will continue to be steadily implemented, and necessary measures will be taken in the light of the situation.

(2) Update of the analysis plans

The growing demand for analysis as the decommissioning process progresses must be handled flexibly and systematic preparations must be made so that the decommissioning work does not stagnate due to analysis. The NRA has prepared the Risk reduction target map, which listed (secondary) waste generated by water treatment, rubbles, building dismantling waste as priority risk reduction fields. It also refers to the analysis that needs to be completed to achieve the "ideal situation to be realized " In response to that, TEPCO identified waste with high priority for analysis based on the progress of analysis and risks associated with storage and management, and formulated the characterization policy and analysis plan in 2023 according to the characteristics of each waste. In addition, after integrating and coordinating analysis plans for each type of waste, TEPCO designed the annual development of the necessary analysis capabilities and incorporated them into analysis personnel plans. After that, reflecting the policy and plan presented at the Technical Meeting on the Examination of the Implementation Plan of the Measures for the Specified Reactor Facilities, etc., TEPCO drafted an analysis plan consistent with the method and schedule of addressing issues that should be addressed with the utmost priority for the time being, revised analysis priorities, and updated the number of analyses based on the sampling conditions, etc. In the future, TEPCO will implement the initiatives in the plan and, based on the progress and performance made, will constantly review its analysis plan.

(3) Development of analysis and evaluation methods

Solid waste has the characteristics of many types of waste in huge amounts. Therefore, efficient characterization is necessary. For this reason, we have developed analytical methods to obtain data easily and quickly, and have established methods of characterization with a small amount of analytical data in the subsidized project for decommissioning. As part of this effort, analytical methods that have been accelerated by streamlining and automating pretreatment of sample are being standardized. In addition, efforts are being made to develop analytical methods to deal with various sample forms and the difficult-to-measure nuclides.

(4) Securing facilities for analysis

The JAEA's Radioactive Material Analysis and Research Facility (Laboratories 1 and 2) has the advantage that off-site transportation is not required because the facility is defined as facilities in the peripheral monitoring area of Fukushima Daiichi NPS. For this reason, analyses that require hot cells, such as fuel debris, should be conducted in the Ibaraki area as necessary, and analyses with high promptness should be prioritized on the site of the Fukushima Daiichi NPS and its adjacent areas. It is effective to expand the analysis data under such an assignment of roles according to the characteristics of each facility for analysis.

(5) Securing human resources for analysis

In each facility for analysis, securing and maintaining analytical personnel to continue stable facility operation is a challenge. It is necessary to consider in advance the qualities expected of analytical personnel in various types of analytical work and develop analytical personnel in a planned manner to achieve the required roles appropriately. Because the decommissioning of the Fukushima Daiichi NPS will directly handle unsealed alpha-ray emitters, which are not usually handled by conventional reactors, TEPCO will have to train personnel in fields with little experience in a short period. The development of analytical engineers should be efficiently promoted with the cooperation of relevant organizations with sufficient knowledge and experience in handling alpha-ray emitters. As the demand for analysis is expected to increase in the future, there will be a need for highly skilled personnel capable of analysis planning in anticipation of how the analysis results will be used. Analytical evaluators in charge of this task are required to have the ability to (i) appropriately incorporate the evaluation results into the areas required for the decommissioning process (retrieval method, safeguards, storage/management, and processing/disposal), (ii) provide appropriate instructions for the subsequent sampling, and (iii) logically and accurately understand accident events from analytical results. However, it is difficult for individuals to have all these abilities. Therefore, the Characterization Plan Coordination Council and an Analysis Support Team were organized within NDF (Fig. 12). The Characterization Plan Coordination Council is responsible for confirming analysis plans and providing advice on problem-solving in response to the increased types and numbers of objects to be analyzed. The Analysis Support Team, consisting of researchers and engineers with extensive experience and knowledge in analytical practice, is to examine and discuss specific R&D approaches and the methods to check reliable analytical techniques in order to solve problems. The first meeting of the Analysis Coordination Meeting and the Analysis Support Team was held in August 2023. For example, discussions have been held on proficiency tests for improving the credibility of analysis data, and in response to that, the NDF is considering test methods to confirm analytical techniques for solid waste. As trial retrieval of fuel debris is to start, preparations are being made for establishing a fuel debris analysis evaluation and study working group (WG) in the Analysis Support Team as one of the WGs to address issues.

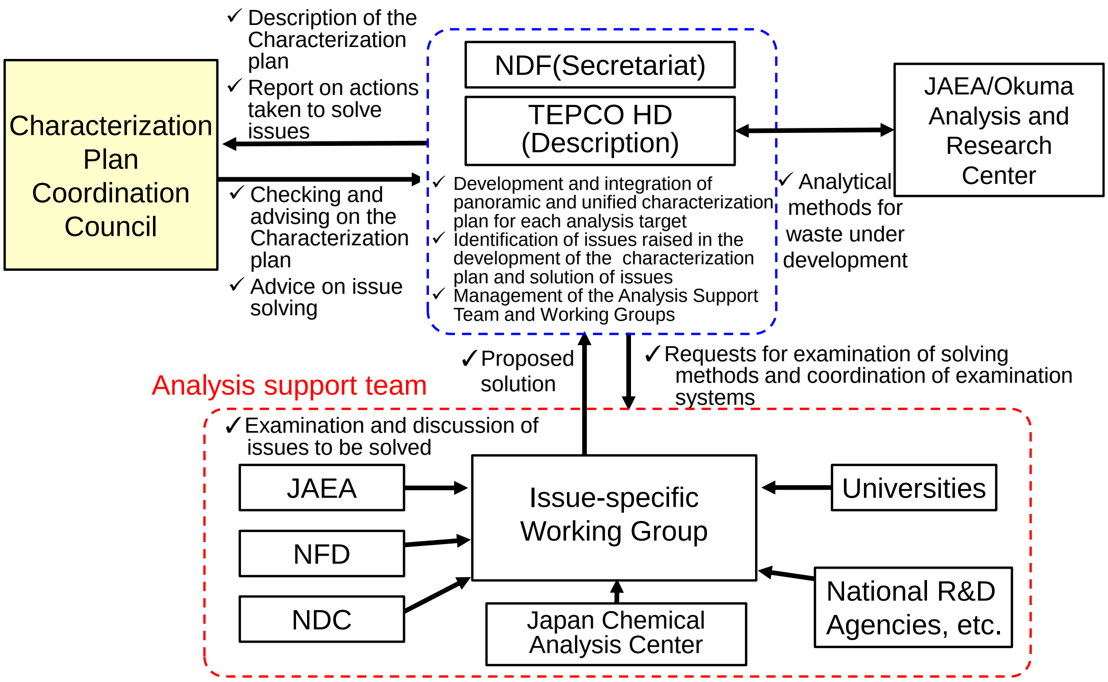


Fig. 12 Role of the Characterization Coordination Council and Analysis Support Team

4.2.2 Improvement of the quality of analysis results

It is difficult to accurately identify and quantify all elements and isotopes of fuel debris up to small components by analysis. As such, it is important to have a multifaceted point of view on the analytical results of samples in consideration of the impact of the error factor. As part of the verification of sample analysis results, through studies in light of existing findings, such as results of analysis, investigation and testing, deriving consistent property evaluations will improve the reliability of analysis results, leading to higher quality of the analysis results. To do so, the JAEA, the NFD, MHI Nuclear Development Corporation, and Tohoku University have been cooperating to conduct chemical analysis and structural analysis using the same samples since FY 2020. Currently, Ibaraki area offices are performing to analyze the Three Mile Island Unit 2 reactor (TMI-2) debris using the latest technologies to expand the fuel debris data.

As for solid waste, to perform characterization of all solid waste which exists in large amounts using the limited analytical data, an efficient approach to ensure the required accuracy will be essential, and efforts are being made to establish an efficient analytical evaluation method. One of the indicators for the quality of analytical data is the accuracy such as the uncertainty and the lower limit of detection, but accuracy and measurement time are interrelated, and it is expected that increasing the measurement time can improve the accuracy. However, if measurements take weeks or months, it is difficult to keep up with the increasing volume of analysis. Therefore, according to the analytical purpose, objects to be analyzed, and analytical method, it is also important to properly select the accuracy, measurement time, and measurement frequency based on the concerned analysis method.

4.2.3 Diversification of analytical techniques to increase sample size and volume

(1) Comprehensive evaluation by diversified analysis and measurement methods

Since density, hardness, and other items cannot be measured for micro or very small quantity of samples, it is necessary to increase the size and quantity of samples in accordance with the progress of the fuel debris retrieval process. Analysis in hot cells is time-consuming, and the amount of use for each nuclide handled is specified, making it difficult to analyze large quantities. Therefore, it is necessary not only to focus on increasing the quantity of analysis in hot cells but also to diversify analysis and measurement methods. It is effective to assess the analysis items obtained by other methods, consider complementing analysis items depending on the use of the analysis results, and make comprehensive evaluation.

(2) Use of sample analysis and non-destructive assays

Although methods to evaluate the amount of nuclear fuel or radioactivity without destroying the sample (hereinafter referred to as “non-destructive assays”) can measure fewer items, the measurement time is shorter than that of sample analysis, and a larger quantity can be measured per measurement. Moreover, in non-destructive assays, measurement can be performed with the object stored in a sealed container for prevention of spread of contamination, which has the advantage of no radioactive liquid waste generated. However, since fuel debris has impediments to nondestructive assays, such as neutron absorbers, it is necessary to verify the extent to which these impediments affect measurements. Therefore, technology development aiming at on-site application is underway through simulation analysis and actual measurement tests. If this non-destructive assay can quantify the nuclear fuel of the fuel debris in the container, prompt analyses can compensate for the small number of samples to be analyzed. When increasing the number of analyses, it is desirable to keep the range of uncertainty in the properties of fuel debris as small as possible while increasing information about the samples, including the coordinate information at sample collection, to improve the reliability of the data.

(3) Improvement in number of analyses

During fuel debris retrieval, it is necessary to collect and analyze a large number of samples for monitoring the contamination status. The larger the number of samples, the proportionally the longer the overall time required for analysis, including pretreatment, and this can hinder the monitoring of the contamination status. Aiming at the rapidness and efficiency improvement in the analysis of nuclear fuel materials, and difficult-to-measure nuclides, etc., the technology development for automatic quantification of these materials is being made at the same time.

While it is important to increase the number of sample analyzed to obtain an overall understanding of any sample, it is also important to improve the number of samples collected through the development of collection equipment, etc., since the number of samples collected is insufficient for samples that are difficult to collect themselves.

4.3 Summary of analysis strategies

4.3.1 Analysis of fuel debris

So far, in preparation for trial retrieval of fuel debris, establishment of a fuel debris analysis system, improvement of the accuracy of analysis results, and domestic and international discussions have been progressing. In regard to fuel debris analysis during trial retrieval, it has been determined that the facilities in the Ibaraki area are capable of sufficiently handling that. However, in the subsequent gradual expansion of fuel debris retrieval, the number of samples to be analyzed will keep increasing, and therefore the establishment of the Radioactive Material Analysis and Research Facility Laboratory-2 needs to be steadily promoted to ensure reliable analysis of samples. For further expansion of the retrieval scale, it is important to consider establishing a comprehensive analysis facility and to collaborate with the technological development of non-destructive assay systems and simplified analysis. In addition, a study is underway on acquisition of data related to processing/disposal using sampled fuel debris.

4.3.2 Analysis of solid waste

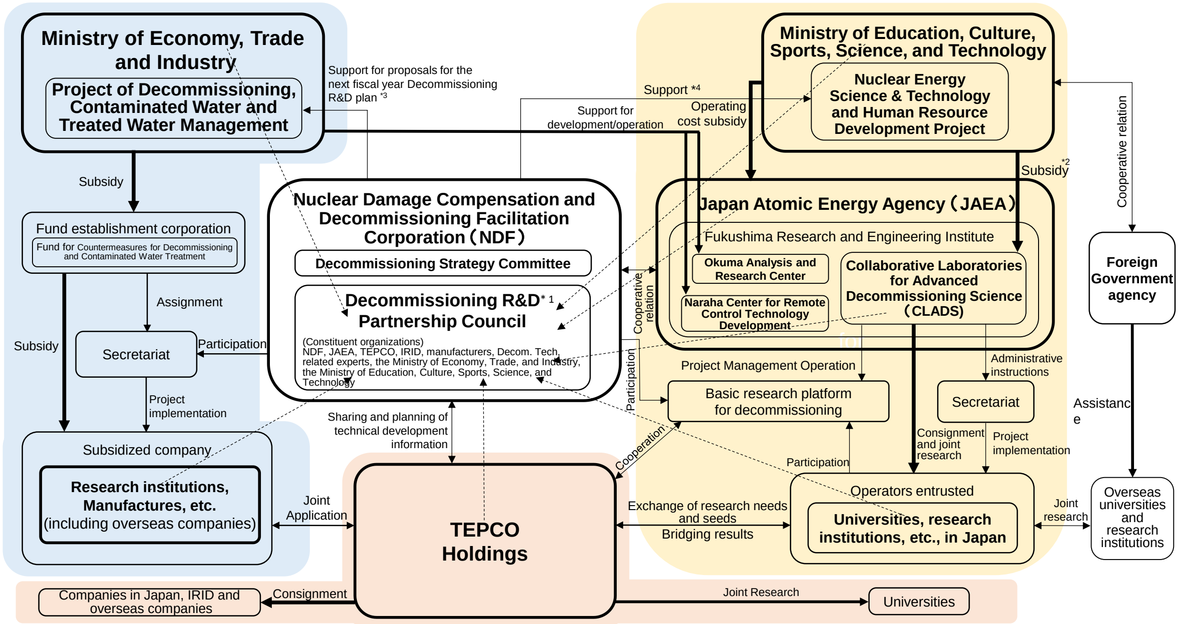
As for the analysis of solid waste, although operation of the Radioactive Material Analysis and Research Facility Laboratory-1 of JAEA has started, the facility for analysis of the Ibaraki area is also put in use for steady and efficient analysis. While analysis data are efficiently acquired based on the analysis plan formulated and revised by TEPCO, considerations are given to the sampling method for high activity waste. In addition, since solid waste is extremely large in quantity, development of a simple and rapid analysis technique will be continued, and establishment of a method of characterization with less analytical data will be pursued, utilizing analysis planning methods using the DQO process and Bayesian statistics or statistical inventory estimation methods. Development of analysis personnel and establishment of a comprehensive analysis facility will also be continued.

5. Efforts to facilitate research and development for decommissioning of the Fukushima Daiichi NPS

5.1 Significance and the current status of research and development

At present, based on the recommendations about the selection of fuel debris retrieval methods made by the Sub-Committee in March 2024, it is necessary to prioritize and accelerate research and development on fuel debris retrieval in consideration of the practical application. For application research and practical application research for decommissioning, the government provides support for the R&D carried out by each organization to solve highly difficult issues through the Decommissioning Subsidized Project and to promote basic/fundamental research and human resource development by universities and researching institutions in Japan and overseas through the Nuclear Energy Science & Technology and Human Resource Development Project (hereinafter referred to as “the World Intelligence Project”). In addition to discussing R&D medium-and-long-term plan and the next fiscal year’s decommissioning R&D plan and supporting the World Intelligence Project, NDF has also established the Decommissioning R&D Partnership Council to strengthen coordination between basic/fundamental research and practical application research (Fig.).

Given that the progress of investigation inside the reactors has clarified on-site needs in decommissioning and TEPCO has begun full-scale feasibility study for fuel debris retrieval, since FY 2023, the leading players in the Decommissioning Subsidized Project have been shifting from the current International Research Institute for Nuclear Decommissioning (hereinafter referred to as the “IRID”)-centered structure to a new R&D system where researching institutions and manufacturers are the key implementers based on TEPCO’s needs. While TEPCO proceeds with feasibility study, the relevant organizations (TEPCO, JAEA, NDF, etc.) will be required to study issues including basic/fundamental research and to prioritize and accelerate R&D and technological development in the Decommissioning Subsidized Project, the World Intelligence Project, and TEPCO’s independent technological development. In addition, regarding the status of R&D and human resource development at the Fukushima Institute for Research, Education and Innovation (F-REI), we will also work together to share information among TEPCO, F-REI, and NDF, based on the fact that F-REI is considering research and development of robots that can be used for decommissioning.



*1 The Decommissioning R&D Partnership Council is established in the NDF based on the determination by Team for Countermeasures for Decommissioning and Contaminated Water Treatment.
*2 Although the subsidy for the World Intelligence Project for Nuclear S&T and Human Resource Development is delivered to JAEA, it is expressed as what is delivered to CLADS, to make it easier to understand.
*3 With regard to the Project of Decommissioning and Contaminated Water Management, based on the policy in the Mid-and-Long-term Roadmap or Strategic Plan and the progress situation of research and development, the NDF formulates a draft plan of the next research and development, and the Ministry of Economy, Trade, and Industry determines it.
*4 NDF participates as a member in a steering committee of the World Intelligence Project for Nuclear S&T and Human Resource Development.
* The arrow drawn in a thick solid line indicates expenditures such as research expenses and operating expenses (excluding facilities expenses), the arrow drawn in a thin solid line indicates a cooperative relation, etc., and the arrow drawn in a dotted line indicates the participation in the Decommissioning R&D Partnership Council.
* Each organization has cooperative relations with foreign organizations based on MOU, etc., respectively.

Fig. 13 Overview of the R&D structure of the decommissioning of Fukushima Daiichi NPS

5.2 Key issues and strategies

5.2.1 R&D medium-and-long-term plan

NDF and TEPCO have been preparing the R&D medium-and-long-term plan for the decommissioning of the Fukushima Daiichi NPS. The plan overlooks the overall research and development in the next 10 years for decommissioning, so that R&D activities for decommissioning of Fukushima Daiichi NPS can be promoted comprehensively, systematically, and efficiently. In FY 2023, TEPCO, Tousou Mirai Technology Co. Ltd., JAEA, and NDF started activities to share issues in the decommissioning R&D (hereinafter referred to as the “Four Party Cooperative Activities”), and since have been reflecting the study results on the R&D medium-and-long-term plan. In FY 2024, in response to the recommendations on the selection of retrieval method made by the Sub-Committee, a task team established through the Four Party Cooperative Activities will proceed with studies on issues including basic/fundamental research and on specific approach to implementation, and the results will be reflected on the R&D medium-and-long-term plan.

5.2.2 Initiatives for the Project of Decommissioning, Contaminated Water and Treated Water Management

In FY 2011, immediately after the accident at the Fukushima Daiichi NPS, the Japanese government started initiatives to support R&D to solve various issues pertaining to the decommissioning. In FY 2013, the Japanese government launched the Subsidized project for Decommissioning to solve technically challenging issues for decommissioning, and has since been supporting R&D conducted by business operators.

In order to promote smooth and steady implementation of the subsidized project for decommissioning, NDF formulates the next fiscal year's decommissioning R&D plan for the next two years on an annual basis. In the plan, past results are evaluated to identify issues whose level of achievement should be improved and emerging issues, and technical issues are organized by selecting issues from the viewpoints of necessity and priority, among issues raised by the public in response to requests for information (hereinafter referred to as "RFI") that were made to widely solicit information on the details to be addressed toward the decommissioning. In FY 2024, in addition to these, based on the recommendations on the selection of fuel debris retrieval method made by the Sub-Committee, selection will be made focusing on technical issues pertaining to the retrieval method that shall be worked on in the future.

As the leading players in the subsidized project for decommissioning have shifted from IRID to researching institutions and manufacturers, NDF launched RFI in FY 2022 and reviews of the subsidized project for decommissioning in FY 2023, enhancing its support in proposal of projects to address R&D tasks and improvement of actual site applicability of the subsidized project for decommissioning.

5.2.3 Promotion of cooperation between decommissioning sites and universities/ researching institutions

MEXT has been promoting basic/fundamental research and human resource development activities, which contribute to problem-solving including decommissioning of the Fukushima Daiichi NPS, in the World Intelligence Project led by the Collaborative Laboratories for Advanced Decommissioning Science of Fukushima Research and Engineering Institute, Japan Atomic Energy Agency (JAEA/CLADS) targeting universities and researching institutions.

It is the key to enhance and promote further coordination of basic/fundamental research and practical application research in achieving breakthroughs in solving issues and improving the safety and efficiency of decommissioning work in the future. To this end, at the occasions of the Four Party Cooperative Activities, NDF will hold discussions on the issues of fuel debris retrieval method, etc., and on specific measures to bring basic/fundamental research to practical application.

In order to make the long-term decommissioning of the Fukushima Daiichi NPS proceed steadier, it is essential to develop fundamental technologies and collect basic data, develop R&D infrastructure through building up research centers, facilities and installations and developing human resource, and accumulate technological knowledge. The JAEA, with JAEA/CLADS as its core, is forming a network in which human resources from universities, researching institutions, and industries in Japan and overseas can interact with each other, to work on R&D, and is proceeding with the operation and construction of the Naraha Center for Remote Control Technology Development (Full-scale mock-up test building) of JAEA and the Okuma Analysis and Research Center (Radioactive Material Analysis and Research Facilities) of JAEA.

6. Activities to support our technical strategy

6.1 Capabilities, organization, and personnel to proceed with decommissioning

6.1.1 Ensuring the capability and organization that TEPCO should possess as the owner of the Fukushima Daiichi Nuclear Power Station

6.1.1.1 Significance and current status of decommissioning project management

In project-type work, such as decommissioning work at the Fukushima Daiichi NPS, the series of tasks consists of clarifying the objectives (i.e., what to do by when for what), determining the specific work content as a means to achieve the objectives, checking the safety and efficiency of the work, designing/manufacturing/building necessary equipment, ensuring the necessary personnel, and using them to achieve the objectives. Thus, the significance of project management is to clarify the objectives, means, required resources and timelines, and then, to systematically manage project execution in order to accomplish the objectives.

TEPCO has been working to build and strengthen its project management system, which was reorganized in April 2020. Project-based organization management has been almost established through four years of operation. Now that it is in phase 3-[1], the decommissioning work becomes more difficult and uncertain, and in order to smoothly coordinate and align the entire project with a view to the medium- to long-term, it will be more important than ever that the relevant organizations will further strengthen a management framework in cooperation with each other towards the goal to be achieved, and increase the collective strength. Examples of major initiatives by TEPCO up to FY 2023 include reviewing the organization to appropriately respond to changes in on-site situation and the needs of society and local communities, strengthening of risk management, and the preparation of a long-term plan for decommissioning (Mid-and Long-term Decommissioning Action Plan).

6.1.1.2 Capability an owner should possess

As stated in the Fourth Special Business Plan, TEPCO should acquire its owner's engineering capabilities. Additionally, in view of the peculiarities of the Fukushima Daiichi NPS, it requires abilities for upgrading the overall decommissioning strategy and for advancing coexistence of reconstruction and decommissioning.

In the following paragraphs, the capabilities that should be strategically enhanced by TEPCO in the future, as NDF believes, are described. Instead of addressing only the issues pointed out, regarding the capabilities required for all activities from the development of the decommissioning project strategy and plan to its implementation, TEPCO should consider what should be acquired in priority among such capabilities and continue taking a proactive approach for the acquisition.

(1) Establishment of safety first and engineering based on safety and operator’s perspectives

In view of the peculiarities of the Fukushima Daiichi NPS, TEPCO needs to continue instilling the safety-first approach. Then, it is necessary to establish a process in which operators who are familiar with the site should be based on the actual situation of the site, check the safety comprehensively, determine the appropriate general safety requirements for the site, and work on it. The overall capability required for this purpose, including field capabilities, is engineering based on safety and operator’s perspectives, and it goes without saying that TEPCO is required to further enhance this capability.

(2) Investigation capability at the upstream side of the project

In decommissioning work at the Fukushima Daiichi NPS, which the upstream design standards are not determined, the cases have been acknowledged, where the project returned to the process that reexamines what functions should be achieved and what general safety requirements need to be satisfied for that after the project advances.

In the future, TEPCO should clarify the significance and objectives of the project (what to do by when and for what) and general safety requirements, develop a comprehensive waste-related plan covering its generation control, reuse, etc., and ensure the feasibility of the project. To this end, in the decommissioning process from its planning to implementation, enhancing the investigation capability is needed, especially at the upstream side.

(3) Capability to upgrade project management

Larger, more complex, and highly uncertain high-difficulty projects are expected in the future, and in such situations, it will be difficult for TEPCO to proceed with work only by simple buying (buying), which is to say, by just deciding specifications, prices, and schedules, and procuring goods and services. To adapt to this situation, TEPCO should upgrade its project management, including the relationship with the contractor and the manner of the contract in the case of making a new product (making).

(4) Nuclear security management capability

With regard to improvement actions in response to the physical protection incidents that occurred at the Kashiwazaki-Kariwa, although the situation is different from that of the Fukushima Daiichi NPS in many ways, it is necessary to ensure that the same measures are taken to the aspects in common to make improvements.

6.1.1.3 Initiatives related to organization

In order for TEPCO to further promote “coexistence of reconstruction and decommissioning”, all employees, both inside and outside the Fukushima Daiichi NPS, must share the same aspirations and sense of responsibility regarding how TEPCO can contribute to this region, and must do their best to transcend organizational barriers.

In order to achieve this, TEPCO decided to consider integrating and reorganizing the head office of Fukushima Daini NPS, which currently belong to the Nuclear Power and Site Headquarters, into Fukushima Daiichi Decontamination and Decommissioning Engineering Company, and in July 2023, the Office of Organizational Restructuring Preparation was established as the umbrella organization for this. NDF also regards these TEPCO efforts positively, and will support the activities so that TEPCO will step up progress to achieve coexistence of reconstruction and decommissioning as the integration and reorganization advance.

6.1.2 Building collaborative relationship with business partners

6.1.2.1 Strengthen procurement management capabilities for long-term decommissioning projects

TEPCO inaugurated a procurement department in July 2024, for the purpose of enhancing the procurement capability by consolidating procurement organizations to centralize procurement, as well as improving the efficiency of contracting operations.

Although it is an important management task for TEPCO to enhance its own procurement capability, in order for TEPCO to maintain and manage the supply chain for the decommissioning work, which has been going on for decades due to the high uncertainty of fuel debris retrieval, etc., it is important to effectively utilize the procurement capabilities of business partners in addition to strengthening the procurement capabilities of the company itself. TEPCO needs to further strengthen its supply chain system in cooperation with its business partners. The supply chain system for the decommissioning of Fukushima Daiichi is basically built in cooperation between TEPCO, which will be placing orders, and its business partners, which will be receiving orders. However, it is essential that the government and NDF also provide necessary support in cooperation.

6.1.2.2 Consideration of ideal on-site management in coordination with partner companies[5]

TEPCO has been working on securing safety and maintaining and improving the quality of operations. However, consecutive incidents occurred including physical contamination during the cleaning of additionally installed ALPS pipes, etc. TEPCO does not merely treat human errors as individual problems, but also takes them seriously as a management issue. While taking into account examples from other industries and the opinions of outside experts, TEPCO thoroughly analyzes whether there are common factors that could cause human errors leading to high radiation risks. At the same time, TEPCO does not hesitate to invest in the introduction of hardware and systems that can prevent human errors. In addition, after the incident of the system shutdown of the on-site power supply system A, work inspections were conducted on all works at the Fukushima Daiichi NPS, and risk factors and protective measures were confirmed.

[5] Among TEPCO's client firms, those engaged in on-site work at the Fukushima Daiichi NPS are called "partner companies".

In addition to the above, TEPCO is building a system to bolster the areas of training and control, for the purpose of further improving safety and quality of the water treatment process, TEPCO embarked on organizational reinforcement including the establishment of the Water Treatment Center that centrally and continuously upgrades water treatment systems and remodels them to improve their maintainability. TEPCO is working on recurrence prevention with a sense of urgency.

TEPCO proceeds with these operations by concluding contracts with prime contractors. These contracts always have requirements for ensuring safety and quality of work. Meanwhile, in order to safely promote the whole decommissioning project, as the responsibility of the owner (orderer), TEPCO is tasked to supervise all operations and carefully check for any discrepancies from the contracts in terms of safety and quality. Therefore, it is important that TEPCO takes comprehensive responsibility while partner companies fulfill their own responsibilities to thoroughly ensure safety and quality.

However, it is difficult for TEPCO alone to continuously ensure safety and quality of operations for a long period of time at complicated worksites changes daily, leaving little to no room for routine work. In addition to exercising ingenuity in forming a contracting system and agreements for all levels of companies engaged in a operation to function with the same objective, TEPCO shall consider working together with partner companies in developing an environment necessary for attaining the objective by, for example, enhancing equipment and management to make worksites safer and introducing a sustainable and level contracting method under which partner companies can comfortably keep working on securing and developing human resources from a long-term perspective.

6.1.3 Securing human resources who engage in the decommissioning, fostering the next generation to handle the decommissioning, and promoting public understanding

To keep working on the decommissioning of the Fukushima Daiichi NPS over a long period of time, it is extremely important that TEPCO systematically secures and develops the human resources needed on its own initiative. For the decommissioning of the Fukushima Daiichi NPS, it is also important to bring human resources with diverse backgrounds and expertise not only in nuclear science but in other science and technology fields into the project. In order to continuously secure and develop such human resources, relevant organizations need to work together with the worksite to steadily promote initiatives for developing the next generation at different educational levels.

To proceed with the decommissioning smoothly and steadily, it is essential to gain understanding of the people widely and continuously. Therefore, it is important to provide opportunities for many people to know decommissioning efforts, in addition to securing opportunities to learn about related information.

6.1.3.1 Initiatives to recruit and develop personnel at TEPCO

(1) Short-term efforts

The decommissioning project at the Fukushima Daiichi NPS is at the phase of undertaking the trial retrieval of fuel debris, the entire workload of the plant is also increasing in line with the gradual expansion of fuel debris retrieval.

Thus, TEPCO is actively recruiting, in addition to that, it is required that its leaders clarify work priorities and promote resources allocation according to the priorities, and development of human resources should be promoted to enhance versatility and productivity of existing personnel. It is essential for TEPCO to make efforts to obtain necessary outputs with limited resources, such as by continuing its existing kaizen activities and by promoting education, training, and Digital Transformation (DX).

(2) Medium- and long-term initiatives

The integration of the Fukushima Daiichi Decontamination and Decommissioning Engineering Company and the Fukushima Daini NPS, which TEPCO has been working on, is also crucial in the sense that it aims to optimize the use of personnel beyond the boundaries of business sites through organizational restructuring. The consolidation should be accompanied by the diversification of personnel, standardization and streamlining of business operations, and efforts to ensure the necessary personnel.

In decommissioning work where the workloads are expected to increase from now on, TEPCO itself should determine what type of and when personnel will be needed in the medium- to long-term, and clearly present the necessity at an early stage so that the company can carry out the activities to recruit personnel from inside and outside the company widely through various channels.

In view of the fact that decommissioning is a long-term activity, TEPCO needs to work to cultivate leaders who will be responsible for decommissioning in a planned and systematic manner from a medium- to long-term standpoint. It is undeniable that leaders in charge of unprecedented and difficult decommissioning projects, in particular, require a higher level of courage and people skills. In addition, they need to possess a keen sense of perception that anticipates the changing business environment as well as the ability to adapt to change, and the ability to learn.

NDF believes that it is useful to benchmark similar programs being conducted overseas in its human resource development activities through collaboration with external organizations.

6.1.3.2 Fostering the next generation who will be responsible for the future decommissioning of Fukushima Daiichi NPS

Universities/researching institutions tasked with basic/fundamental research are expected to develop human resources to make a quick response when technical issues requiring scientific knowledge occur. It is also important that universities/researching institutions share awareness of issues faced by the decommissioning on-site. In the World Intelligence Project, MEXT is promoting R & D and human resource development to meet the needs of the decommissioning site over the medium to long term by integrating and collaborating knowledge from diverse fields in Japan and overseas across organizational boundaries. In “the Decommissioning research program based on development of research human resources” of the World Intelligence Project, the third phase of the program[6] has been started in FY2024.

For junior and high school students in the earlier stage of secondary education, which is the stage before higher education, it is important to introduce the appealing points of engaging in the nuclear energy field, including decommissioning, and to make efforts to attract their technical interest with a focus on decommissioning, as well as to improve their understanding of the decommissioning and reconstruction of the Fukushima Daiichi NPS, and in a broad sense, of the career path in science and technology fields. The secondary education stage is an important preparatory stage before participating in and contributing to society while developing one's individuality and exploring one's interests. It is of great significance for students in this stage to be inspired by researchers, engineers, and science teachers who are active in society and to leverage such inspiration to make independent choices and decide their career paths.

6.1.3.3 Dissemination of basic knowledge and promoting people's understanding of decommissioning and the radiation safety involved in decommissioning

Acquiring a basic knowledge of the decommissioning of Fukushima Daiichi NPS is fundamental to promote public understanding of decommissioning and important. In particular, from the perspective of enhancing resilience to various disasters in the future, opportunities to learn should be secured depending on children’s developmental stage. For this reason, the government has been promoting teachers and staff training and on-site classes on radiation, and the use of radiological supplementary readers. Furthermore, from the perspective of informing the public of the current status of decommissioning, TEPCO is accepting visitors to the Fukushima Daiichi NPS and TEPCO should continue to actively promote efforts to arouse public interest and contribute to better understanding of the decommissioning process by accurately communicating the current status of the decommissioning of the Fukushima Daiichi NPS.

6.2 Strengthening international cooperation

6.2.1 Significance and the current status of international cooperation

In order to steadily proceed with the decommissioning of the Fukushima Daiichi NPS, which deals with highly difficult engineering issues, it is important to utilize the experience gained through preceding decommissioning activities of past nuclear facilities (hereinafter referred to as “legacy

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[6] In the framework of the Decommissioning research program based on development of research human resources as part of the World Intelligence Project, CLADS has conducted the 1st Phase of the program (from 2014 to 2019) with the objective of building a human resource development system in universities and the 2nd Phase of the program (from 2019 to 2023) with the objective of building a system to mobilize for CLADS knowledge and experience of various fields accumulated in universities.

site") located overseas. Under such recognition, bilateral cooperation has been promoted in line with the circumstances of each country and the experience of decommissioning activities around the world has been incorporated by utilizing the framework of multilateral cooperation through international organizations such as the IAEA and the OECD/NEA. In addition, Japan is expected to fulfill part of its responsibility to the international community by sharing the experiences gained through the decommissioning with other countries, and maintaining relationships with relevant overseas organizations by concluding cooperation agreements with them. It is important to gain international understanding as our country moves forward with the decommissioning of Fukushima Daiichi NPS. To this end, in addition to gathering of wisdom and sharing of experience, it is necessary to disseminate transparent information to the international community and to engage in continuous dialogue.

Each of the Japanese government, TEPCO, and NDF is working with their counterparts in technical cooperation and sharing information, experience, lessons learned, etc., with the aim of building a strong cooperative relationship for long-term decommissioning in the future. Moreover, from the viewpoint of maintaining a foundation for utilizing and collecting the knowledge of experts from around the world, NDF annually holds the International Forum on the Decommissioning of the Fukushima Daiichi NPS (hereinafter referred to as the "International Forum"), continuously disseminating information on the current status of and issues related to decommissioning, in addition to participating in various conferences and technical committees of international organizations.

6.2.2 Key issues and strategies

(1) Integrating and giving back the wisdom and knowledge from around the world

To ensure the steady progress of the decommissioning of Fukushima Daiichi NPS, it is necessary to learn lessons from the decommissioning activity examples of legacy sites and apply them to decommissioning, and to utilize world-class technologies and human resources. TEPCO has stationed staff at legacy sites to gain practical experience and periodically conducts visits and information exchanges with decommissioning-related organizations and companies. Meanwhile, NDF has established long-term partnerships with the public decommissioning implementing agencies with a central role in each country, and needs to collect wisdom and knowledge, including lessons learned from decommissioning of overseas legacy sites. Based on these, the decommissioning should be undertaken with the following three strategies taken into consideration.

① Cooperation with counterparts

It is important for TEPCO, as an entity that makes progress of the decommissioning steadily, and NDF, as an organization that provides advice and guidance to ensure proper and steady implementation of decommissioning from a medium-to-long-term perspective, to maintain and strengthen relationships with their counterparts.

② Utilization of a broad range of technological information that contributes to the decommissioning

In order to seek the application of further technology in decommissioning, collecting technical information should be continued, and to obtain cooperation from countries that do not use nuclear technology and experts in industries other than the nuclear industry.

③ Continuation of mutually beneficial relationship

Ensuring the mutually beneficial relationships will be continued while being conscious of returning the expertise and results accumulated domestically so far to the international community. It is also effective to maintain interest in decommissioning technology by responding not only to accidents or decommissioning, but also to aspects such as applications to issues other than nuclear power.

(2) Maintaining and developing the international community's understanding, interest and cooperation in decommissioning

The challenge is to maintain and develop the international community's understanding, interest and cooperation in order to bring together the world's wisdom in the decommissioning of Fukushima Daiichi NPS and to limit the risk of confrontational structures to the implementation of decommissioning as far as possible.

International opinion can considerably impact the progress and success of decommissioning. Therefore, it is necessary to define a policy for international cooperation, taking into account the impact that the spread of misperceptions regarding the decommissioning of the Fukushima Daiichi NPS overseas affects the decommissioning progress. The strategy for gaining international understanding needs to be divided into ① an approach for experts and ② an approach for the general public.

① Approach to experts

It is fundamental for the international community's understanding that experts abroad accurately understand the scientific and technical validity of the efforts toward the decommissioning of the Fukushima Daiichi NPS. In order to maintain interest outside Japan, dialogue and exchange with foreign counterparts should be activated outside Japan among technology implementers, technology developers, and researchers involved in the practical implementation of the technology, beyond the public and private sectors.

In order to contribute to the formation of international public opinion based on scientific and accurate information, recognizing the importance of having experts around the world correctly understand the situation, Japan should continue to work with government agencies and international organizations to disseminate information and engage in dialogue with relevant parties regarding the achievements of its efforts toward decommissioning.

② Approaches to the general public

The interests of the recipients of the information have changed since the time of the accident, and there are some gaps between countries in the amount of knowledge and information that are the basis of understanding. Moreover, Japan should actively provide information to countries other than advanced nuclear nations in cooperation with international organizations.

Regarding the discharge of ALPS-treated water into the sea, the Ministry of Foreign Affairs of Japan (MOFA) and the Ministry of Economy, Trade and Industry (METI) are taking the lead in actively publicizing the issue, based on scientific perspectives. In addition, the Japanese government has implemented concerted measures, such as responding to IAEA reviews by METI and the NRA.

It is difficult to proceed with the decommissioning of the Fukushima Daiichi NPS without global understanding. We will endeavor to build trust by actively and strategically returning to the international community the knowledge, etc. obtained in the course of conducting the decommissioning at the Fukushima Daiichi NPS. Furthermore, as a responsibility of Japan, which caused the accident, the government and other domestic organizations concerned must continue to provide highly transparent and accurate information on decommissioning of nuclear power stations, which should be strategically addressed in the future.

6.3 Stakeholder involvement

6.3.1 Significance and the current status of local community engagement

The fundamental principle for the decommissioning of the Fukushima Daiichi NPS is coexisting with reconstruction (“coexistence of reconstruction and decommissioning”). The decommissioning should never hinder reconstruction efforts such as returning home, moving to, and settling in Fukushima due to anxiety and distrust of the decommissioning. It is important to sincerely listen to local residents’ concerns and questions, and to deepen their understanding and remove their anxiety about the decommissioning process through two-way communication. To this end, the government is exchanging views with concerned local organizations at The Fukushima Advisory Board on Decommissioning, Contaminated Water and Treated Water, and other organized meetings; disseminating information through videos, websites, brochures, and other media summarizing the current status of decommissioning; and holding information meetings and roundtable discussions for local residents and relevant local governments. NDF also holds international forums where local residents and other participants exchange frank opinions on decommissioning with related organizations. TEPCO actively disseminates information utilizing its website and brochures, and accepts visitors to the Fukushima Daiichi NPS.

In order to carry through the decommissioning over a long period of time, continued cooperation by local and other companies is essential. For that reason, inviting local companies to participate in and revitalizing decommissioning-related industries in this region will be important pillars in contributing to Fukushima’s reconstruction. Approximately 3,500 to 4,700 workers are engaged in work at the Fukushima Daiichi NPS, the local employment rate is about 70%. In this way, the decommissioning project is supported by the people of the region. Therefore, based on the “Commitment to the people of Fukushima for coexistence of reconstruction and decommissioning” formulated at the end of March 2020, TEPCO has organized its initiatives for the industrial cluster for decommissioning into three categories: (1) increasing participation of local companies, (2) stepping up support for local companies, and (3) creating new industries locally, and phased in the initiatives. With regard to (1) and (2), TEPCO has promoted these initiatives in cooperation with the Fukushima Innovation Coast Framework Promotion Organization and the Fukushima Sousou Reconstruction Promotion Organization. The contents of the “Medium-to-Long-Term Outlook” prepared in September 2020 have been updated to reflect the progress of the decommissioning work, and briefing sessions have been held for local enterprises and commercial and industrial organizations. With regard to (3), in order to build a system for integrated implementation of decommissioning projects locally in the 2020s, Tousou Mirai Manufacturing Corporation to manufacture core products including spent fuel cask necessary for decommissioning, and Tousou Mirai Technology Co. Ltd. to conduct basic design including spent fuel casks necessary for further expansion of the retrieval scale were established in October 2022.

6.3.2 Key issues and strategies

（1） Communication issues and strategies

Since misunderstandings, concerns, and reputational damages caused by dissemination of inappropriate information regarding the decommissioning will hinder the reconstruction of Fukushima, TEPCO will face the issue of disseminating the current status of the decommissioning accurately and in a timely and easy-to-understand manner. To that end, along with initiatives to have face-to-face communications such as inspection tours and roundtable discussion sessions, TEPCO should continue to strengthen communication that is possible even in non-face-to-face and non-contact situations by use of tools like online conference systems.

Another issue for the government, NDF, and TEPCO is to make appropriate coordination and build trust with local communities by providing information more carefully. For this purpose, while proactively working in cooperation with related organizations, accurate information should be provided in an easy-to-understand and courteous manner by communicating in both directions through dialogue. Especially, regarding the disposal of ALPS-treated water, the Japanese government has been implementing measures to prevent and overcome reputational damages based on the ‘Progress and the directions of future measures regarding “Basic Policy on handling of ALPS treated water at the Tokyo Electric Power Company Holdings’ Fukushima Daiichi Nuclear Power Station”’ (formulated on August 30, 2024) and other stipulations.

（2） Issues and strategies related to the creation of a regional industrial and economic base through decommissioning

As the initiative for “(3) creating new industries locally” is relatively large-scale investment, and it is required to steadily promote and strengthen the initiative. On the other hand, since manufacture of highly-functional products requires advanced technology, the issue is whether this will lead to the active participation of local companies. For the time being, the current initiatives including “(1) increasing participation of local companies” and “(2) supporting local companies to step up” should be continued and strengthened, while carefully explaining the study status of new decommissioning-related facilities to the local governments, commercial and industrial organizations, etc., to gain their understanding and cooperation.

Some local companies do not necessarily want to be the prime contractors, but would prefer to enter the market as a subcontractor to gain technology and experience. It is also important for TEPCO and prime contractors to unitedly consider various specific initiatives including means of ordering and contracting while properly understanding such intentions and needs of local companies. TEPCO should continue to show its stance of working with the local communities and Fukushima to advance the decommissioning work over the long term, by considering measures that will make it easier for local companies to participate in the work and measures that will enable local companies to continue to place orders of a certain scale.

To steadily promote efforts of coexistence with local community, TEPCO needs to further strengthen its partnership and collaboration with local governments and relevant local organizations, along with close internal cooperation. NDF will support TEPCO's efforts to promote regional coexistence, and will work to strengthen coordination and collaboration with local governments and relevant local organizations, as well.