Technical Strategic Plan 2025

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

Overview

October 30, 2025

Nuclear Damage Compensation and
Decommissioning Facilitation Corporation

Table of Contents

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, and efforts toward full-scale decommissioning work that will begin in Phase 3 are being implemented with the cooperation of the relevant organizations.

In Phase 3, the project has shifted from primarily implementing emergency measures, such as preventing the impact of accidents from spreading, to systematically reducing long-term risks arising from fuel debris retrieval and other operations. Accordingly, Tokyo Electric Power Company Holdings, Inc. (hereinafter referred to as "TEPCO") presented a general picture of the preparatory work required for the full-scale fuel debris retrieval from Unit 3. As the degree of difficulty and complexity of the decommissioning work is gradually becoming apparent, TEPCO will take an uncompromising stance toward executing the project and review the implementation structure of the decommissioning work to date, recognizing that completing the decommissioning project is its paramount responsibility. Specifically, TEPCO will: (1) acquire the ability to develop and manage a long-term decommissioning strategy, as well as the processes based on the strategy, and manage the decommissioning work at a high level; (2) Establish a collaborative structure with partner companies for work involving high exposure or safety risk, including worker training and work management, in order to make decommissioning sustainable; (3) Continually secure the necessary human resources to support this project; and (4) Create more opportunities for local companies to participate in decommissioning work in order to achieve the coexistence of reconstruction and decommissioning. Nuclear Damage Compensation and Decommissioning Facilitation Corporation (hereinafter referred to as “NDF”) will also strengthen its functions and provide guidance and advice in line with the decommissioning project phase transition.

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.

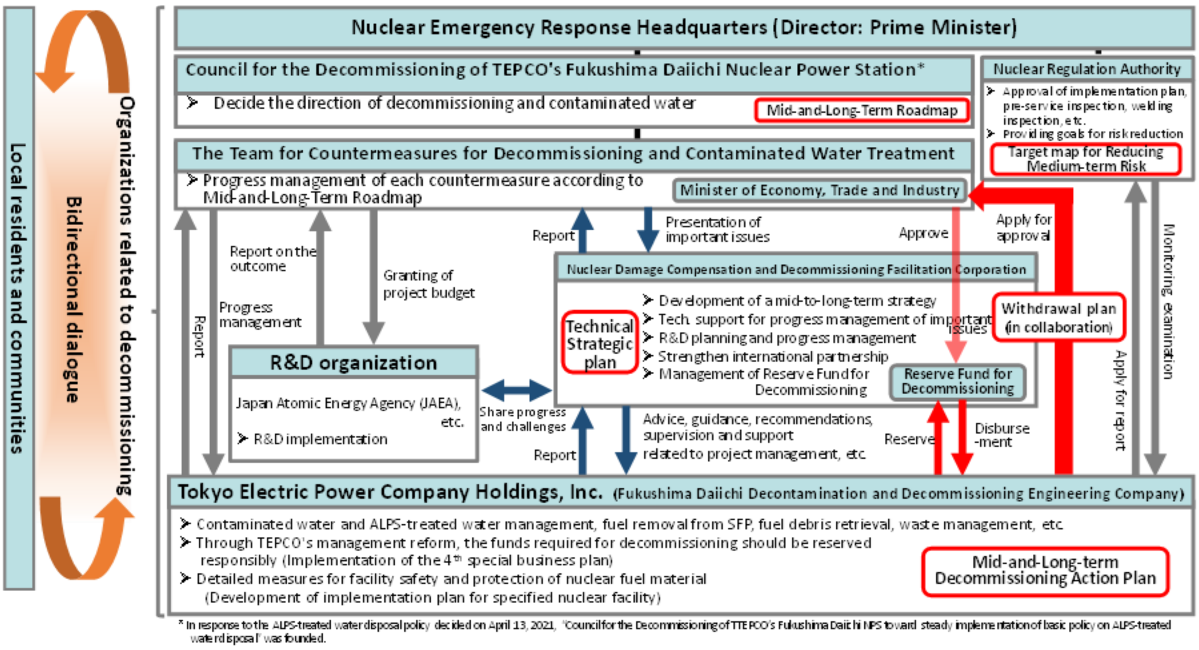
- Providing a solid technical basis for the Mid-and-Long-term Roadmap and contributing to its smooth and steady implementation, consideration of revisions, and

- 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.

1.1 Structures and systems toward the decommissioning of the Fukushima Daiichi NPS

In order to safely and steadily conduct the decommissioning of the Fukushima Daiichi NPS, each relevant organization is working together on the efforts based on their respective roles as shown in Fig.1.



〔Source: NDF〕

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

1.2 Matters to be discussed in Phase 3

The decommissioning of the Fukushima Daiichi NPS finally entered Phase 3 of the Mid-and-Long-term Roadmap in September 2024. This also means that the project has shifted from the phase focused primarily on short-term risk reduction through post-accident emergency response to the phase focused primarily on mid-to-long-term risk reduction, where various decommissioning operations, including fuel debris retrieval and environmental improvement necessary for advancing its operation, and installation of additional decommissioning systems proceed simultaneously.

1.2.1 Status of activities for achieving the goals set out in the Mid-and-Long-term Roadmap

The decommissioning of the Fukushima Daiichi Nuclear Power Station is being carried out based on the Mid-and-Long-term Roadmap. The Mid-and-Long-term Roadmap states that “it is necessary to take measures to reduce risks throughout the entire facility.” In addition, based on the NRA's Target Map for Reducing Risks map, TEPCO has classified risks and is responding to them in order of priority according to their magnitude. Table 1 shows the risk classification based on the Mid-and-Long-term Roadmap according to their sources.

Table 1 Risk classification according to source of risk

No.	Risk classification	Specific example/action policy
1	Relatively high risk with high priority	Fuel in spent fuel pools, highly contaminated water
		Take countermeasures as soon as possible while also paying full attention to the situation regarding the facilities, dispersion and leakage of radioactive materials, exposure of workers, and other risks.
2	Risks are unlikely to manifest immediately, but may grow due to hasty handling	Fuel debris
		Accumulate the necessary information and technology, and make thorough preparations. Then, implement countermeasures in a safe, reliable, and careful manner while also paying full attention to aging, external impacts, exposure of workers, and other risks.
3	Increased risk is unlikely in the future, but appropriate decommissioning efforts are required	Solid waste
		Implement long-term countermeasures while also paying full attention to aging, dispersion and leakage of radioactive materials, exposure of workers, and other risks.

〔Prepared by NDF based on the Mid-and-Long-term Roadmap〕

To achieve the goals set out in the Mid-and-Long-term Roadmap, TEPCO has been working to strengthen its organizational structure. First, in June 2011, the Fukushima Daiichi Stabilization Center was established on the Fukushima Daini NPS site to consolidate the accident response that had been implemented at the Fukushima Daiichi NPS and the head office and to strengthen the accident response capabilities.

Subsequently, TEPCO established the Fukushima Daiichi Decontamination and Decommissioning Engineering Company in April 2014 to clarify responsibility and centralize organizations for decommissioning and contaminated water management. The Fukushima Daiichi Decontamination and Decommissioning Engineering Company introduced a project management system in April 2020, and since then, has continued to proceed with decommissioning while strengthening its structure through reorganization. Although incidents continue to occur, there have been no serious incidents, such as events with off-site consequences or fatal accidents, since 2016. Under this structure, overall progress has been made steadily toward the goals set out in the Mid-and-Long-term Roadmap. Although some delays have occurred, the target of reducing the amount of stagnant water in buildings by half from the end of FY2020 has been achieved as planned, and the reduction in the amount of contaminated water generated has been achieved ahead of schedule.

Table 1 below shows the progress and achievement status of specific examples according to risk classification.

① Relatively high risk with high priority

- Fuel in spent fuel pools

A large amount of spent fuel generated by each reactor's operation was stored in the respective spent fuel pool (hereinafter referred to as "SFP") located in each reactor building at the Fukushima Daiichi NPS. In Units 1 to 3, where the primary containment vessel (hereinafter referred to as "PCV") were suffered a loss of the containment function, and Units 1, 3 and 4, which experienced hydrogen explosions, the structural integrity of the reactor building and the maintenance of the SFP cooling function were called into question from a long-term perspective. Therefore, the policy of removing the spent fuel from the SFPs was immediately decided upon. The removal of spent fuel has been completed at Units 3 and 4, and preparations for Units 1 and 2 are progressing steadily.

In Units 5 and 6, which did not experience hydrogen explosion, the removal of spent fuel from their SFPs is underway for long-term risk reduction. The removal of spent fuel from Unit 6 has been completed, and only fresh fuel remains. Spent fuel removal will continue with the aim of completing it by the end of 2031, including Unit 5.

- Contaminated water, etc.

Specific measures to address contaminated water include reducing the amount of contaminated water generated, reducing stagnant water in buildings, accelerating treatment with multi-nuclide removal equipment, and discharging treated water into the sea.

Contaminated water is a mixture of cooling water for cooling fuel debris, rainwater and groundwater flowing into the reactor building (building inflow water), and water pumped up from the seaward side (2.5 meters above sea level) to the reactor building (building transfer water). In the past, the maximum amount of contaminated water generated was approximately 490 m^3 /day (annual average). As measures to control the amount of contaminated water generated, efforts such as the construction of land-side impermeable walls, operation of sub-drains, and control of rainwater inflow (paving, roof repair, etc.) are being made, and as a result, the average amount of contaminated water generated in FY 2024 was reduced to approximately 70 m^3 /day (approximately 80 m^3 /day when corrected to rainfall in a normal year). In an effort to further reduce the amount of contaminated water generated, the goal of reducing it to approximately 50 to 70 m^3 /day by the end of FY 2028 has been set. Although the cooling water does not affect the amount of contaminated water generated because it continues to circulate, the amount of cooling water injected decreases due to the reduced decay heat of the fuel debris

To reduce stagnant water in buildings, the contaminated water in the reactor building has been isolated to prevent its transfer to other buildings. Other than the reactor buildings in Units 1 to 3, the high-temperature incinerator building (hereinafter referred to as the "HTI"), and the process main building (hereinafter referred to as the “PMB”), floor surface has been exposed. Efforts have also been made to lower the water level in the reactor buildings. The goal of "reducing the stagnant water in the reactor buildings to about half the level at the end of FY 2020 between FY 2022 and FY 2024" was set achieved in March 2023.

The strontium treated water[1] stored in the flange tank was treated by the multi-nuclide removal equipment (hereinafter referred to as “ALPS”) by the end of FY2018, and the strontium treated water currently being generated is stored in the welded tanks and is being treated by ALPS. ALPS-treated water[2] has been continuously discharged into the sea since August 2023, resulting in a reduced amount of ALPS-treated water stored in the welded tanks.

On the basement floor of the buildings, there are deposits in the form of sludge and resins stored in tanks since before the earthquake, and it is necessary to process them appropriately before treating the contaminated water, as well. One specific countermeasure for sludge is to dehydrate and store them in containers after accumulating and collecting them, and then store them in a stable condition for the time being.

The zeolite sandbags that are part of the deposits, and which were placed on the basement floors of PMB and HTI in the days shortly after the accident, will be collected and contained in containers using a remote device. Collection has just begun in the HTI. For the waste sludge stored in the tank in the PMB, the design of the waste sludge collection system and radiation dose reduction in the PMB are progressing in order to facilitate transfer to higher ground. The ALPS slurry generated during water treatment is currently stored and managed strictly in storage containers (HICs), and preparations for stabilization (dehydration treatment) are underway.

② Risks are unlikely to manifest immediately, but may grow due to hasty handling

- Fuel debris

“Trial retrieval” started in Unit 2 in September 2024 and was completed in November 2024 and April 2025. A detailed analysis of the retrieved fuel debris is in progress. In addition, preparations are underway for internal investigations and fuel debris retrieval using a robotic arm.

Currently, TEPCO is proceeding with a study for “further expansion of the retrieval scale” in Unit 3.

③ Increased risk is unlikely in the future, but appropriate decommissioning efforts are required

- Solid waste

NDF presented the Technical Prospects of Processing/Disposal Method and Technology Related to its Safety in 2021, according to the target of the Mid-and-Long-term Roadmap. Based

[1] Water treated with a cesium adsorption device to remove cesium and strontium from contaminated water.
[2] Water obtained by treating strontium-treated water with ALPS until the level of radioactive substances other than tritium are reliably below regulatory standards.

on this, the Waste Stream, which describes the flow of waste from source to disposal, is under development.

Meanwhile, the development of systems and facilities, such as solid waste storage facilities, is underway to "eliminate the temporary outdoor storage of rubble and other materials," and is expected to be achieved by the end of FY 2028. Currently, the state of storage is shifting to safe indoor storage.

1.2.2 Issues to be addressed in preparation for full-scale fuel debris retrieval

Fuel debris retrieval is literally an unprecedented technological challenge that involves difficult remote operations in a severe, high-radiation dose environment. TEPCO needs to collaborate with partner companies at each stage from survey to 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 conditions for storage 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 what specific disposal should be, detailed 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 of expanding the scale of 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 its first direct dialogues with the residents at 13 municipalities in June 2024 regarding the Report on the Sub-Committee for the Evaluation of Fuel Debris Retrieval Methods (hereinafter referred to as “Sub-Committee Report”) issued in March 2024, and exchanged opinions with the residents in 16 municipalities from November to December 2024 and March to August 2025. 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 the intention was indicated that they wanted us to continue dialogs while making improvements going forward.

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 and expand the target areas.

1.3 Key Points and Major Changes in the Technical Strategic Plan 2025

The key points of the Technical Strategic Plan 2025 are as follows.

- Implementation status of “trial retrieval” in Unit 2 (fuel debris sampling and results of fuel debris analysis) and evaluation of troubles
- Implementation status of engineering based on the Sub-Committee Report on the retrieval methods for Unit 3
- Implementation status of the discharge of ALPS-treated water into the sea and analysis

The Technical Strategic Plan 2025 mainly makes the following changes.

- Moved the description of “Issues to be discussed in Phase 3” from Chapter 2 to Chapter 1.
- Organize the approach to risk in Chapter 2 and clarify the description.
- To clarify the technical strategy in Chapters 3 and 4, include the "how" perspective in the objectives.

2. Concept for reducing risks 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. In Chapter 2, unless otherwise specified, radiation exposure risk to the public is referred to as simply "risk." and when it includes risks to workers (occupational accidents, exposure associated with work), it is referred to as "risk in decommissioning work."

2.1.1 Risk reduction measures to be addressed in Phase 3

Regarding fuel debris retrieval, preparation for “further expansion of the retrieval scale” to what will be full-scale decommissioning work is promoted in Phase 3. Currently, temperatures and pressures inside the PCV are stable. However, once fuel debris retrieval starts, conditions inside the PCVs will change, and risks that were previously perceived as small may increase, or previously unknown risks may become apparent. To effectively reduce risks with a view to “further expansion of the retrieval scale”, the challenge lies in improving the ability to observe conditions inside the PCVs. Therefore, despite the high degree of difficulty in installing on site, consideration should be given to expanding the type and number of monitoring targets.

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[3]”, an index of the likelihood of an event occurring. The current risk levels assigned to the respective risk sources are

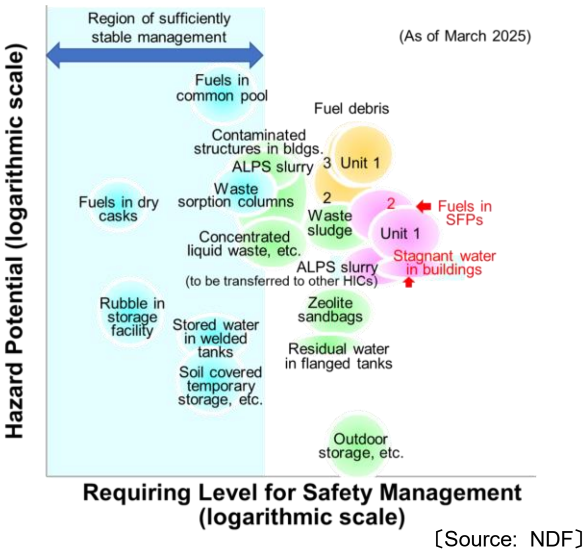


Fig. 2 Risk levels posed by major risk sources at the Fukushima Daiichi NPS

[3] 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

expressed in Fig. 2 with “Hazard Potential” and “Requiring Level for Safety Management” as the axes[4].

The writings in red in Fig. 2 present the risk sources that have changed significantly from the evaluation of the Technical Strategic Plan 2024 (as of March 2024), the origin of the arrow indicates the location reported in the Technical Strategic Plan 2024.

The major changes are (1) a decrease in the Requiring Level for Safety Management for fuel in the SFP (Unit 2) due to an improved work environment after the completion of a series of work, including the removal of obstacles, decontamination, and the installation of shielding on the operating floor of the SFP in Unit 2 , and (2) an increased Hazard Potential from the stagnant water in buildings due to increased radioactivity concentrations of the stagnant water resulting from the transfer of the retained water in the S/C (partial contamination of "contaminated structures inside buildings") to the underground stagnant water in the reactor building due to lowering the S/C water level in Unit 1. Regarding (2), lowering of the S/C water level is assumed that the radioactive concentration increased because the transfer of water inside the S/C to the underground stagnant water in the reactor building due to leakage from the system connected to the lower part of the S/C. It is expected that the radioactivity concentration in the stagnant water in the underground area of the reactor building will decrease, and the increased Hazard Potential will also decrease due to the reduced amount of S/C water transferred to the reactor building after lowering the S/C water level in Unit 1 and continuing purification treatment. The improved seismic resistance of the PCV resulting from the lowered S/C water level in Unit 1 can reduce the risk of deterioration in the containment performance for fuel debris (in Unit 1) due to damage to the PCV.

2.2.2 Risk reduction strategy

2.2.2.1 Interim targets of the risk reduction strategy

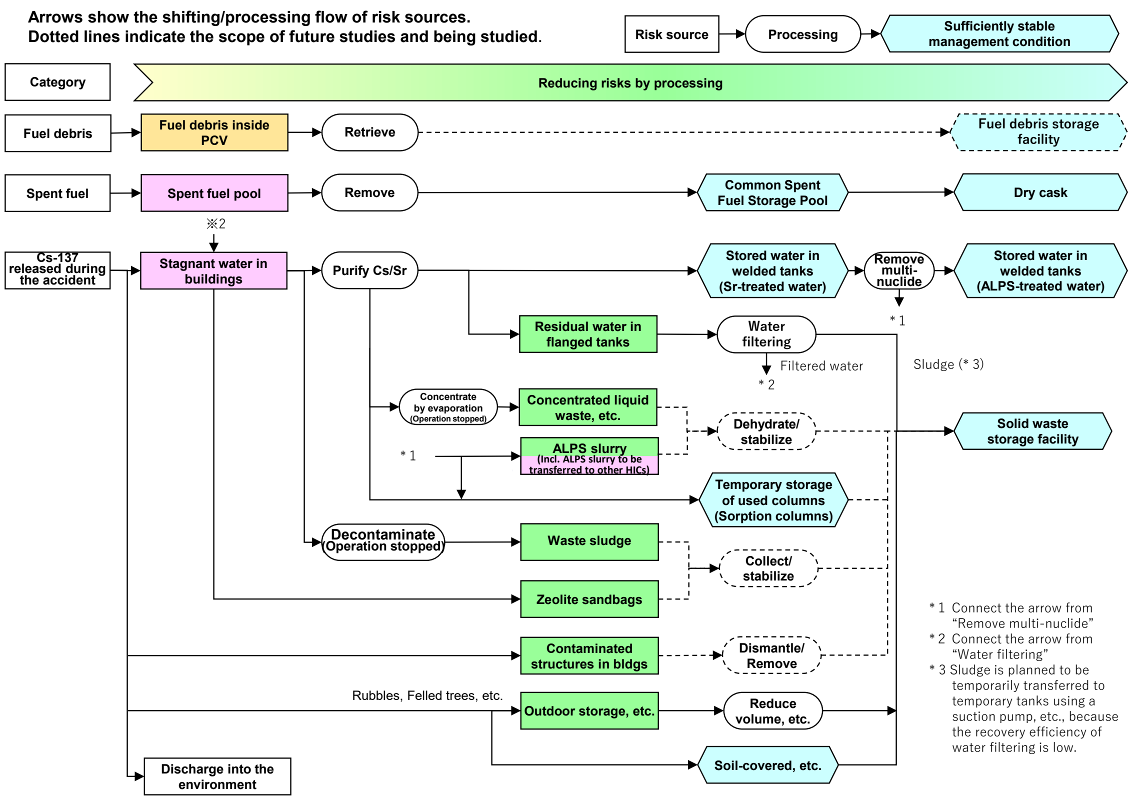
Measures for risk reduction include the reduction of the “Hazard Potential” and the reduction of the “Requiring Level for Safety Management”, reduction of the “Requiring Level for Safety Management” is generally considered to be easily realized from an engineering perspective. The immediate goal, therefore, is to reduce Requiring Level for Safety Management and bring it into a “sufficiently stable management” region (Fig. 2) 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

[4] 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.

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.

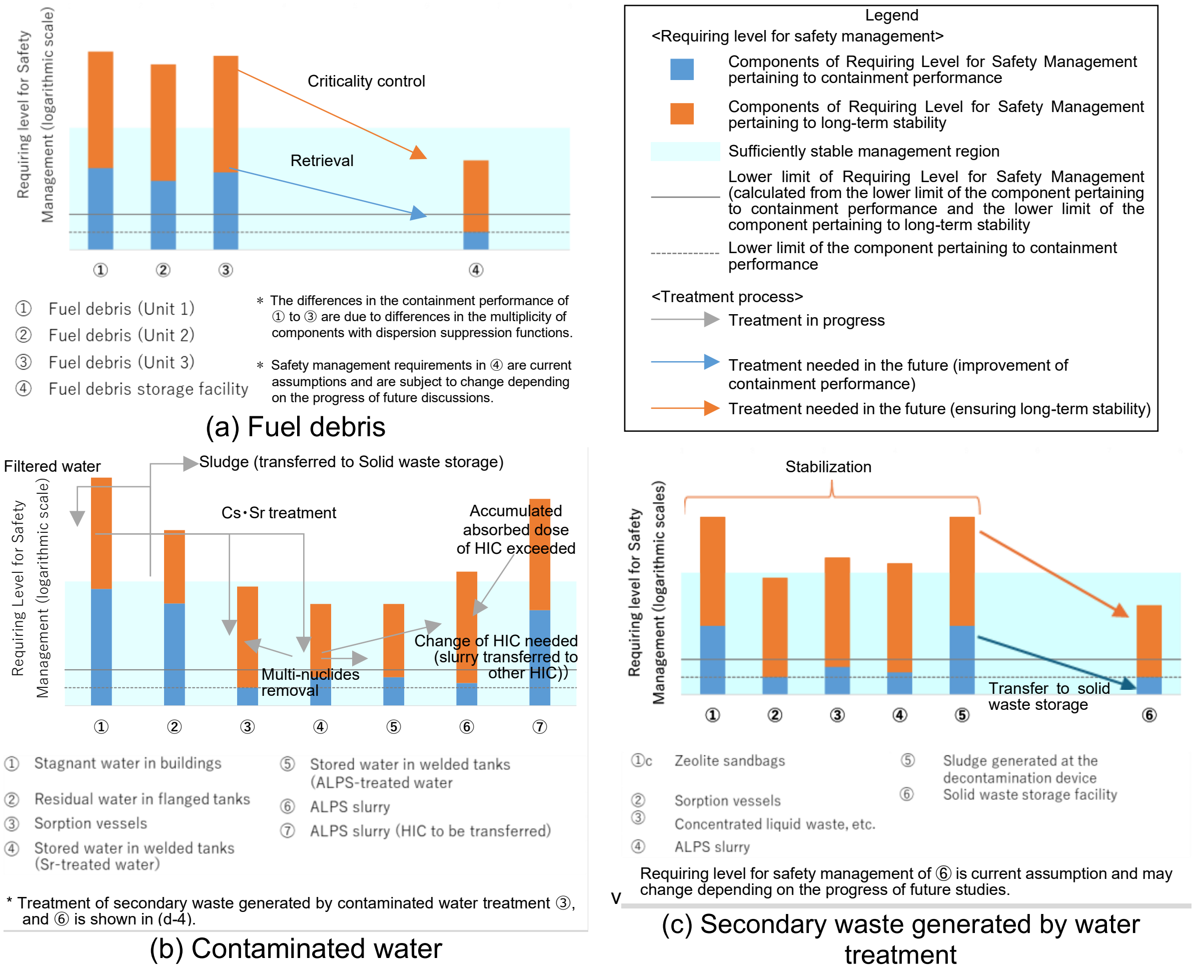
Fig. 4 shows the transition of Requiring Level for Safety Management corresponding to risk sources and their treatment process indicated in the flow graphically by risk source category. The Requiring Level for Safety Management shown is divided into two components, one for containment performance and the other for long-term stability, which corresponds 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 treatment 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 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 risk source are detailed in Chapter 3.



〔Source: NDF〕

Fig. 3 Risk reduction process for major risk sources and the progress (as of March 2025)



〔Source: NDF〕

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

2.3 Approach to risk reduction in decommissioning work

2.3.1 Basic policy for risk reduction in decommissioning work - Instillation and thorough implementation of a safety-first policy -

The information required for the decommissioning of the Fukushima Daiichi NPS, such as plant conditions and the properties and locations, etc. of fuel debris, has high uncertainties. In order to overcome such uncertainties and proceed with decommissioning work, it is important to evaluate and analyze the decommissioning work being implemented from various perspectives and to make comprehensive judgments based on the information obtained, which will lead to reduction in decommissioning work risks.

NDF proposes the following five points of focus when making comprehensive judgments: safe, proven, efficient, timely, and field-oriented.

(Five points of focus)

- Safe — Reduce the risks posed by radioactive materials and prevention of occupational accidents

  (Issues such as containment of radioactive materials (environmental impact), exposure of workers to radiation, the effect of risk reduction, preventive measures of occupational accidents)

- ➢ Proven — Highly reliable and flexible technologies
  (Issues such as conformity to requirements, effectiveness, flexibility against uncertainty and flexible response procedures)
- ➢ Efficient — Use resources effectively (e.g., people, things, money and space)
  (Issues such as reduction of waste generation, cost, efficiency, securing necessary work area and site)
- ➢ Timely — Conscious of time
  (Issues such as the period required for fuel debris retrieval, and long-term integrities of RPV, PCV and buildings)
- ➢ Field-oriented — Comprehensive three-reality policy by checking actual site, actual things, and actual situations
  (Issues such as workability (environment-friendliness, accessibility, and operability), and maintainability (ease of maintenance and troubleshooting))

Comprehensive judgments should be made based on the awareness that “safety” is the most important and overriding priority among these points of focus, and the assumption that safety is ensured. TEPCO needs to be aware that safety is ensured and be held accountable for the details of comprehensive judgments. From the viewpoint of reducing risks in decommissioning work, it is equally important to ensure that all parties involved in decommissioning work understand that safety is paramount and the overriding priority. To achieve this, it is also important for the management at TEPCO to continue communicating directly that “safety is special and requires special attention.” Note that the concept of safety herein covers not only public exposure and the radiological impact on the environment but also worker exposure and occupational safety.

Because the Fukushima Daiichi NPS has the following unique characteristics, it is necessary to give sufficient consideration to how these characteristics affect the focus points when examining each focus point.

Because the Fukushima Daiichi NPS has the following unique characteristics, it is necessary to give sufficient consideration to how these characteristics affect the points of focus when examining each focus point.

- A large amount of radioactive material (including α-ray emitting 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.

2.3.2 Considerations for reducing risks in decommissioning work

2.3.2.1 Ensuring safety throughout the entire decommissioning period

Safety must be the highest priority for all operations and activities related to decommissioning, not just for fuel debris retrieval, with compliance with laws and regulations as a prerequisite. In the course of discussions at the Sub-Committee for the Evaluation of Fuel Debris Retrieval Methods (hereinafter referred to as the "Sub-Committee") to study on the retrieval methods for "further expansion of the retrieval scale", for safety assurance, it has become clear that the highest possible level of safety at each individual step of a process, and to accumulate such efforts, may not necessarily lead to optimal safety assurance throughout the entire decommissioning period. For instance, attempting to eliminate all temporary increases in risks in decommissioning work could significantly lead to a stagnation in the reduction of long-term decommissioning risks (i.e., the cumulative risk over the entire decommissioning period will increase). In order to move forward with the decommissioning, TEPCO should take these issues into account and ensure safety by considering not only the short-term risks in each step of decommissioning work but also the long-term risks in decommissioning work in a balanced manner throughout the decommissioning period.

Furthermore, to ensure safety during the decommissioning period, it is necessary to take into account significant uncertainties in the Fukushima Daiichi NPS. Under such circumstances, equipment design and operation based on conventional, conservative evaluations will make it difficult to optimize protection over the entire decommissioning period. It will also lead to conservative assumptions that deviate from reality, which could result in insufficient consideration and overlooked scenarios to be extracted. In the future, TEPCO, as an operator, needs to consider its approach to safety assurance measures, including designing and operating equipment based on evaluation of the most likely scenarios and preparing to mitigate the effects of situations beyond the evaluated scenarios, by leveraging existing knowledge and acquiring information, and will continue to thoroughly discuss and share understanding with the Nuclear Regulation Authority (hereinafter referred to as the "NRA") as discussed at the NRA Committee (on August 27, 2025)[5]

2.3.2.2 Reduction of occupational safety risks

Multiple incidents have occurred in series since the physical contamination during the cleansing of the additionally installed ALPS pipes in October 2023. The common factor is that the workers actually engaged in the work took occupational safety risks, such as radiation exposure and occupational accidents. While reducing the risks associated with "public exposure and environmental consequences due to the off-site release of radioactive materials", which was one of the "safety" considerations, is a given, this indicates that a higher priority should be placed on

---

[5] NRA, "The 27th meeting proceedings, NRA committee FY2025", August 27, 2025

reducing occupational safety risks in the decommissioning work, including patrols or equipment inspections.

In the future, more challenging tasks, such as fuel debris retrieval, will be required. Therefore, it is necessary to focus more on reducing occupational safety risks for site personnel. To achieve this, TEPCO's commitment to “improving installations and the environment based on the operator/worker-first principle” is a critical issue. In particular, to reduce the occupational safety risks, it is necessary to improve the work environment and develop a work plan by enhancing the risk scenario and evaluation for each work task beforehand.

2.3.2.3 Safety-oriented planning by incorporating the operator's perspective

The decommissioning of the Fukushima Daiichi NPS, which will further expand in scale in the future, takes place in a situation in which the plant status has not been fully assessed in the first place, and significant uncertainties still exist. Therefore, full attention should be paid to on site feasibility. To reduce risks in the decommissioning work, it is essential to incorporate the information gained from the actual site, as well as the viewpoints and judgments of individuals and organizations familiar with the actual site that are responsible for practical operations, including on-site operation, maintenance, radiation control, instrumentation, and analysis, that is, operator's perspective, into equipment design and work planning adequately and flexibly.

In the process of determining this, it is important to decide on the retrieval methods/equipment to be adopted eventually through the cycle of “defining the safety standards (safety perspective)”, “indicating the feasibility on-site (operator’s perspective)”, and “examining and discussing as a project (project management)”. The safety perspective and the operator’s perspective are not independent of each other. While implementing the above cycle, it is important to determine the retrieval methods and equipment to be adopted eventually.

2.3.2.4 Step-by-step approach to overcoming uncertainties

As a consequence of the hydrogen explosion at the time of the accident and the contamination caused by the released radioactive material, the current status of the Fukushima Daiichi NPS cannot be fully assessed. Therefore, it is necessary to proceed with the equipment design and decommissioning work under the situation with significant uncertainties. Considering the possibility of aging and future natural events (such as earthquakes or tsunamis), it is necessary to accelerate the assessment and reduction of uncertainties.

In such circumstances, a step-by-step approach is effective. The plan is to divide the work activities into several steps, execute the work in the first step on a scale that can limit decommissioning risks to within the anticipated range, analyze and evaluate the information gained during this period, and then expand the scale of work based on the results, and then execute the work in the subsequent step[6]. With this approach, it is also necessary to set the target for monitoring

[6] This is also used in the UK, for example, for the decommissioned facilities in Sellafield, and it is called Lead & Learn.

from the viewpoint of what kind of information should be obtained in each step of the work for effective use for the work in the subsequent step, and to establish in advance the threshold for restricting the work and mobile equipment procedures in case of an emergency.

Hereafter, it is recommended that a policy be established to clarify that information obtained from monitoring, and its analysis and evaluation, should be fully incorporated and accumulated as knowledge in efforts to reduce the risks in the decommissioning work. Accumulating successful/unsuccessful experience gained in the process as a track record enables a gradual reduction in the major uncertainties associated with decommissioning work. Because monitoring is important for reducing uncertainties, the development of monitoring technology is also essential.

2.3.2.5 Further strengthening of independent efforts to reduce risks in the decommissioning work

At the Nuclear Regulation Authority meeting held on March 12, 2025, it was decided to introduce the nuclear regulatory inspection system methodology (new inspection system), which has already been implemented at nuclear power reactors, into inspection in the Fukushima Daiichi NPS implementation plan.

Nuclear regulatory inspection is characterized by (1) free access, (2) evaluation based on performance and importance, and (3) promotion of independent efforts by operators through (1) and (2).

As these characteristics demonstrate, TEPCO should first promote independent efforts to reduce the risk of decommissioning work to address nuclear regulatory inspections. For this purpose, it is necessary to further enhance Configuration Management (CM) and the Collective Action Program (CAP) in reference to the initiatives for power reactors that have already been implemented by power companies, and to promote the early detection of risk factors and the prompt implementation of countermeasures commensurate with their importance.

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 the 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 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 Targets

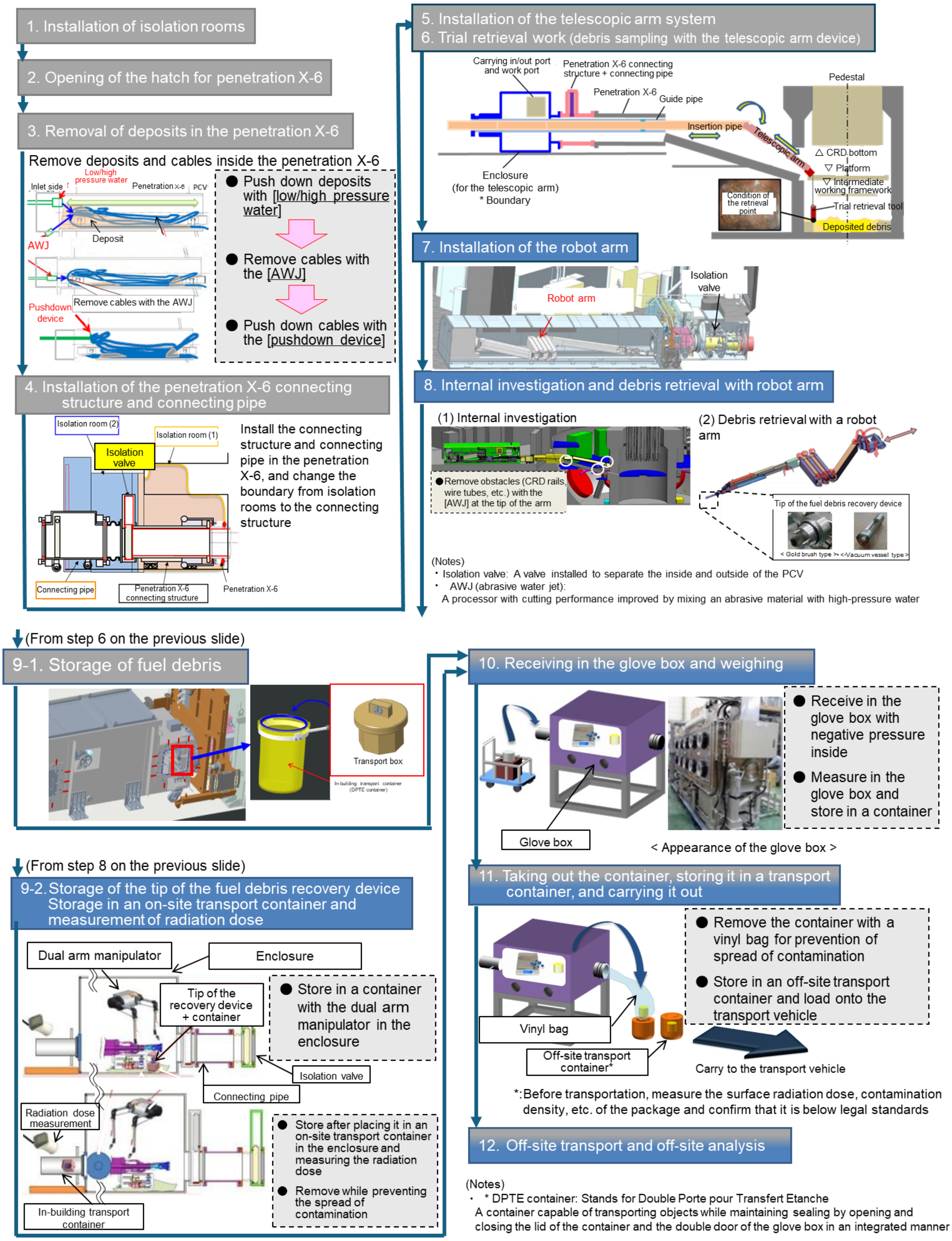
Retrieve fuel debris safely after thorough and careful preparations, and bring it to a state of fully managed stable storage in appropriate storage containers and facilities. To achieve that:

- Promote the internal investigation including “trial retrieval” of fuel debris in Unit 2 and proceed with a series of operations, such as “gradual expansion of fuel debris retrieval”.
- Proceed with internal investigations of the reactor pressure vessels (hereinafter referred to as “RPVs”) and PCVs and improve the environment inside and outside the reactor buildings.
- Utilize the information and experience gained from fuel debris retrieval in Unit 2, internal investigations, research and development, and environmental improvements, etc., for “further expansion of the retrieval scale”, and determine the methods for preparing, retrieving, containing, transferring, and storing fuel debris.

3.1.2 Progress

Unit 1:
To improve the seismic performance of the S/C, the PCV water level has been lowered by decreasing the amount of water injected into the reactor from March 2024, and the water level in the D / W has generally lowered to the floor level. The water level decrease in the S/C was also confirmed, and will continue to be monitored and reflected in the plan for S/C water level decrease. Because of the lowering of the PCV water level, it is estimated that a part of the deposit has been exposed to the air. Due to the possibility that the environment inside the PCV has changed as described above, environmental investigation inside the PCV in the vicinity of penetration (penetration part to the PCV, hereinafter referred to as “penetration”) X-2 was conducted in September 2024 (summer) and February 2025 (winter) in preparation for future surveillance. As a result, the findings showed that haze is more common in winter. The information obtained in this investigation will be reflected in the design of future investigation equipment and the configuration of mock-up testing and training environments.
Unit 2:
TEPCO has been conducting a series of “trial retrieval” operations in stages, as shown in Fig. 5. To collect fuel debris early and reliably, TEPCO has used a telescopic device for collection and completed the first sampling operation on November 7, 2024, and the second sampling operation, which aimed to expand knowledge by increasing the number of fuel debris samples, on April 23, 2025. The internal investigation including "trial retrieval" of fuel debris using a robot-arm is expected to begin in FY 2026 since additional verification was performed following the change in the mounted camera. Although the scale of this work was small, it was confirmed that an on-site configuration in which the hatch of the existing penetration X-6 on the PCV is opened and the containment barrier is extended to the outside of the PCV could be established as the fundamental form of future retrieval work. This knowledge will be utilized not only for the “gradual expansion of fuel debris retrieval” but also for the “further expansion of the retrieval scale” in Unit 3. Fuel debris samples collected in the first “trial retrieval” were transported to off-site facilities for characterization, including the JAEA Oarai Nuclear Engineering Institute, and characterization has begun at these facilities. The size of the first fuel debris sample was about 9 mm × 7 mm, with a mass of 0.693 g and a radiation dose rate of about 8 mSv/h (Gamma rays: stored in a polypropylene container, 1 to 2 cm away from the sample). The results of elemental mapping

show that the sample contains uranium, but its distribution is nonuniform. The distribution of other elements, such as iron, is also nonuniform. Chemical composition analysis showed that the uranium concentration ranged from 30 to 45 mass%, it varies depending on the portion used for analysis. Due to melting and mixing with other materials, this result is lower than that of intact uranium fuel pellets. The result of the U-235 isotope ratio analysis (U-235/total uranium) was approx. 1.9 at% (approx. 1.9 mass%), which is close to the average value of approx. 1.9 mass%, of the uranium isotope ratio (U-235/total uranium) in Unit 2 reactor core calculated at the time of the accident. One characteristic is that the concentration of Cs-137 is about 1/1000 that of the average spent fuel in the core. Since Cesium is highly volatile and water-soluble, it is assumed that Cesium was volatilized during fuel melting or leached into water by subsequent water injection. The size of the second fuel debris sample was about 5 mm × 4 mm, with a mass of 0.187 g and a radiation dose rate of about 0.3 mSv/h (γ-rays were measured at a distance of 1 to 2 cm from the sample in a polypropylene container). Elemental analysis of the surface detected six elements: Uranium (Un), Zirconium (Zr), Ferrum (Fe), Chromium (Cr), Nickel (Ni), and Oxygen (O). Analysis of the fuel debris samples collected by “trial retrieval” is ongoing, and the final results of the characterization will be provided in the future. As was observed in this characterization, the elements and metallographic phases of fuel debris are not uniformly and homogeneously distributed, and they differ between the sampled pieces. Therefore, the analysis results are only one example and not representative of all of the fuel debris, it is important to continue characterization and accumulate data as the planned fuel debris retrieval progresses.
Unit 3:
The penetration X-6 front chamber was investigated for studies to utilize as an effective access route for PCV internal investigation and fuel debris retrieval in the future. As a result of checking camera footage by drilling a hole in the shield and inserting an investigation device, and measuring radiation doses, no molten material was observed adhering to flange surface, and no leakage marks were found from the PCV compared to Unit 2. In addition, the air dose rate was approximately one order of magnitude lower (maximum 124 mSv/h) than Unit 2, and it was presumed that most of the radiation sources were from inside the PCV. Moreover, sampling and analysis of the contained water were conducted to examine methods for radiation dose reduction and to investigate the accident in the control rod drive system hydraulic control unit (HCU). Under normal conditions (prior to the accident), the system is fully flooded, but the contained water samples collected were small in volume (approximately 10 to 50 mL). The analysis results showed that the Cs-137 concentration was in the 10th power [Bq/L] order, and the H-3 concentration was in the 7th power [Bq/L] order, the concentrations were found to be comparable to the results of previous analyses of water contained in the RCW heat exchanger of Unit 1.



(TEPCO material edited by NDF)

The gray color in the work title indicates completed tasks, blue indicates future plans, and gray/blue indicates tasks completed using a telescopic device and future plans for a robot-arm.

Fig. 5 Major work steps for internal investigations including "trial retrieval" of fuel debris

3.1.3 Key issues and technical strategies

3.1.3.1 Fuel debris retrieval strategies in each Unit

Common issue:
• Since each unit has many areas where direct visual information is unavailable, the challenge is to conduct further internal investigation to gain diverse information. Assuming further expansion of the retrieval scale, investigation will proceed while developing and updating the internal investigation plan in the future, while incorporating new investigation technologies to be developed. In particular, it has been demonstrated that small wireless drones are a useful surveillance tool with excellent accessibility, so their use and the use of submersible ROVs will be expanded. Based on the information acquired by these internal investigations, the direction of the fuel debris retrieval strategy should be verified to avoid engineering backtracking and to increase the reliability of the retrieval methods to be selected. • Since work under high radiation doses is required, it is necessary to continuously take measures, including reduction of radiation exposure for all workers, prevention of concentration of worker radiation exposure on specific individuals, securing of human resources from a long-term perspective in operations, development of a radiation exposure assessment system that can streamline work planning and radiation exposure management, and implementation of proficiency training for workers using simulated environment equipment.
Unit 1:
The following findings from the PCV internal investigations should be taken into consideration in proceeding with planning for the “further expansion of the retrieval scale”. ➢ Outside the pedestal, deposits are distributed over a wide area. ➢ At the inner bottom of the pedestal, there are deposits of nearly uniform height and some upper structures such as CRD housing, etc. ➢ A fallen CRD housing (including multiple CRD-related devices) is blocking a part of the opening used to replace the CRD inside the pedestal. ➢ The lower concrete near the pedestal opening (worker access opening) and the inside wall of the pedestal is missing around the entire periphery. Meanwhile, as for the upper concrete, no major damage has been observed on the inner wall of the pedestal.
Unit 2:
• “Trial retrieval” should proceed for the “gradual expansion of fuel debris retrieval”.
Unit 3:
• Considering that the removal of fuel in the SFP has been completed, there is little interference with other operations, and the environment of the reactor building will be improved faster than Unit 1, it has been determined that, ahead of other units, retrieval methods be examined for practical application to “further expand the retrieval scale”.

3.1.3.2 Internal investigation including “trial retrieval”

In the first trial retrieval using a telescopic device, the operation was suspended due to the push-in pipes being connected in the wrong order and the inability to obtain footage from the camera on the tip jig. However, the first retrieval was completed after investigating the cause and implementing countermeasures. In the former case, when working in extremely harsh environments such as high-radiation dose areas, it was noted that in addition to ensuring thorough on-site verification by TEPCO for general preparations, such as transportation and unpacking of pipes, it is necessary to conduct checking with on-site perspective for taking work constraints in high radiation dose environments into consideration and perform job training in simulated environments.

The latter event in which abnormal images were captured by the radiation-resistant camera was assumed that the cause was a large amount of electric charge generated by high radiation doses affecting the board inside the camera. Keeping in mind the possibility of such an unpredictable event in a high radiation dose environment, this event revealed the fact that it is essential to verify the test and other data in consideration of its use in future on-site work. These experience, knowledge, and other related information should be incorporated as lessons for future on-site work. The second fuel debris retrieval work was completed as planned by improving the device based on the experience gained from the first operation and training workers. This was the first fuel debris retrieval at the Fukushima Daiichi NPS, the experience gained during the process from examination to the retrieval operation and the information obtained through the analysis of the retrieved samples will be used in future decommissioning efforts. Internal investigations including “trial retrieval” of fuel debris using the robot-arm are planned for the future.

In preparation for the application of robot-arms in uncertain sites, the issues faced are functional verification checks under various conditions and ensuring that equipment can be saved in an emergency. For this reason, the necessary preparations have been made to ensure that the required functions are satisfied through mock-up tests that simulate the actual site and that identified risks are eliminated. In addition, it should be recognized that mock-up tests do not replicate the current post-accident state entirely, and therefore, necessary measures should be fully prepared for practical application.

Moreover, due to the uncertainty of the conditions inside the PCV, it is assumed that there is a possibility that additional work or rework may be required depending on the actual on-site situation and that work may not go as planned. Bearing this in mind, the work should proceed safely and carefully. Furthermore, each of these operations has no precedent, and the valuable information, experience, etc., gained through them should be leveraged appropriately in subsequent retrieval operations in other units. In addition, it is important to consider in advance troubleshooting and a system for a prompt response to go with it.

3.1.3.3 “Gradual expansion of fuel debris retrieval”

The “gradual expansion of the retrieval scale” requires preparation based on experience and issues identified in “trial retrievals”, with the main objectives being 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 experience in retrieval operations among workers, for the period until “further expansion of the retrieval scale” begins.

3.1.3.4 “Further expansion of the retrieval scale”

Since fuel debris retrieval is an important process in the decommissioning project, and its retrieval in a reliable manner affects the success or failure of the decommissioning project, TEPCO should take responsibility for examining the retrieval methods from a comprehensive standpoint, considering not only their technical feasibility but also resources and processes.

When studying retrieval 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 PCV and RPV

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.

- Appropriate establishment of requirements for ensuring safety: In proceeding with the design study on fuel debris retrieval methods, it is necessary to make a comprehensive judgment from the viewpoint of project promotion, considering the level of safety to be aimed at in the end and the work period required to achieve it. For this reason, it is important to assess the impact if an event that threatens safety occurs, such as an earthquake or criticality, and then to set the requirements appropriately.
- Estimation of information needed to study retrieval methods: On-site information on the location, quantity, and properties of fuel debris, environment (dose rate, contamination density, temperature, humidity, etc.) and PCV internal conditions are required. If such information is unknown, a comprehensive analysis and evaluation are performed based on the estimation by previous internal investigations and analysis, and past knowledge , among other sources, to establish the consideration conditions. These efforts should be continued hereafter to incorporate the expected results into the information used to examine the retrieval methods in order to improve the accuracy of examination. In particular, in “trial retrieval” in Unit 2 and the “gradual expansion of fuel debris retrieval”, new information and knowledge are expected to be obtained from the verification results of the retrieval systems, data on the environmental impact of processing, data on the composition and properties of fuel debris obtained by analyzing more samples, and work and other relevant experience related to safety and exposure at each phase in gradually increasing the retrieval amount, despite the uncertainty of the on-site situation. This information and knowledge will serve as input for the subsequent phases. Valuable information and knowledge obtained from practical application should be appropriately incorporated into the study of retrieval methods, including the design of retrieval, containment, transfer, and storage facilities for “further

expansion of the retrieval scale", as well as safety measures and radiation dose reduction measures.

- Development of fuel debris retrieval scenarios: It is necessary to examine fuel debris retrieval scenarios by each unit and to clarify paths from preparation to retrieval, containment, transfer and storage when examining retrieval methods. In considering fuel debris retrieval scenarios, multiple options are anticipated due to uncertainties at the site and the state of technological development. After reviewing these several paths, it is important to combine and narrow down the paths to take according to the information obtained afterward. However, depending on the information obtained thereafter, it may be determined that the retrieval scenario that has been examined is not reasonable. In such a case, it is necessary to return to the drawing board and review the retrieval scenario.
- Clarification of requirements: The operations, devices, and facilities will be larger, and the scope of construction will be broader. Therefore, the challenge is to perform the examination by overviewing the entire Fukushima Daiichi NPS, including other construction work. 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 systems, groundwater management, waste management, etc.) should be clarified further.
- Issue identification and verification of actual site applicability and technical feasibility: As a method to systematically identify issues latent in the developed retrieval methods, an effective means is to examine the construction sequence (series of procedures) from preparatory work through fuel debris retrieval, maintenance, and completion of fuel debris retrieval to identify issues that may significantly affect the actual site applicability and technical feasibility of each process work. In addition, breaking down the construction sequence as much as possible increases the completeness of the issues to be identified. Moreover, measures to address the identified issues should be examined and verified to ensure their effectiveness before proceeding to the next study phase.
- Setting indicators/criteria for determination: When evaluating retrieval methods, in addition to evaluation to confirm that they meet the target safety level and to check the actual site applicability and technology feasibility based on the five points of focus (safe, proven, efficient, timely, field-oriented), the results of assessment on resources, processes, availability of workers, and social receptivity should also be used as decision indexes. In addition, decision indexes should be defined from the initial stage of studying retrieval methods to clarify the criteria used in evaluation. Information (e.g., exposure assessment reports, structure evaluations) for objectively determining whether the criteria are met should also be clarified in advance.

3.1.3.4.1 Outline of design studies at TEPCO

Starting in FY 2024, TEPCO conducted specific design studies for Unit 3 in accordance with the report of the Sub-Committee, and outlined the results examined for retrieval scenarios, installation planning and processes. Of the results of these studies, the Sub-Committee mainly discussed work details and processes (preparatory process), and other matters related to preparation up to the start of full-scale retrieval, which could be indicated with a certain technical basis. In addition, as for after the full-scale retrieval of fuel debris, as there is currently a high level of uncertainty on site, tasks and installations will be reexamined based on the information obtained from future internal investigations and R&D. First, the Technical Strategic Plan outlines the policy for examining retrieval methods and retrieval scenarios, and provides an overview of TEPCO’s examination results. Next, it describes the process (preparatory process) up to the start of full-scale retrieval, which can currently be provided. In the retrieval scenario, note that future internal investigations, etc., may find new issues due to, for example, a significant difference between the actual fuel debris distribution and the distribution used as the basis of consideration conditions. In that case, retrieval scenarios may be changed, and in some cases the method itself may be retroactively revised.

NDF checked the status of TEPCO's design studies as appropriate, and TEPCO incorporated the results of discussions with NDF into their design studies.

（1） Examination policy for retrieval methods

As indicated in the Sub-Committee Report's recommendations for selecting a retrieval method, the method is based on a combination of the partial submersion method and its options. However, it is appropriate to consider supplementing the issues by leveraging the characteristics of each retrieval method without being bound by conventional methods. Based on this policy, the following shows the policies on which a particular emphasis was placed when examining retrieval methods.

① Access through small opening

Considering the characteristics of the approach to the partial submersion method option, in principle, access to fuel debris should be through a small opening. The small opening allows the use of the shielding function of the existing biological shielding walls, thereby suppressing radiation leakage from within the PCV. This also allows the reduction of the size of equipment with additional shielding functions.

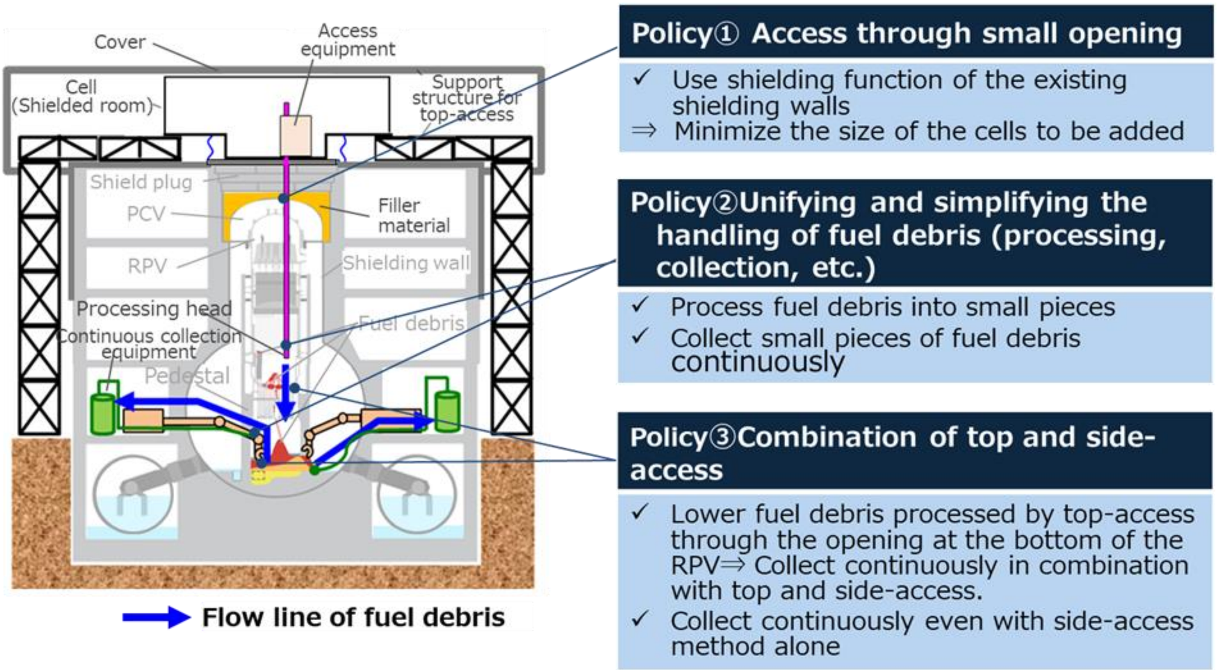
② Unifying and simplifying the handling of fuel debris (processing, collection, etc.)

Considering the characteristics of the approach to the partial submersion method option, a plan will be developed to unify and simplify fuel debris handling, including its processing and collection. One possible measure is to process fuel debris into small pieces, lower the pieces to the bottom of the PCV, and continuously collect the accumulated small fuel debris pieces.

③ Combination of top and side-access

Since the inner PCV can potentially be accessed at an early stage, fuel debris at the bottom of the PCV will be collected using the side-access method alone, ahead of top-access. In addition, continuous collection will be planned to improve processing capability. In the top-access method, access through the small opening (①) will be applied. The plan should be developed so that the route for collecting fuel debris and other materials does not pass through the operating floor in principle, or the cell and the retrieval equipment to be installed on the operating floor should not exceed excessive weight limits. As such, a plan will be made to process fuel debris into small pieces and lower through the opening at the bottom of the RPV, where damage is estimated, into the bottom of the pedestal. Once top-access method is ready, fuel debris is continuously collected in combination with the top and side-access methods.

The images for ① to ③ above are shown below.

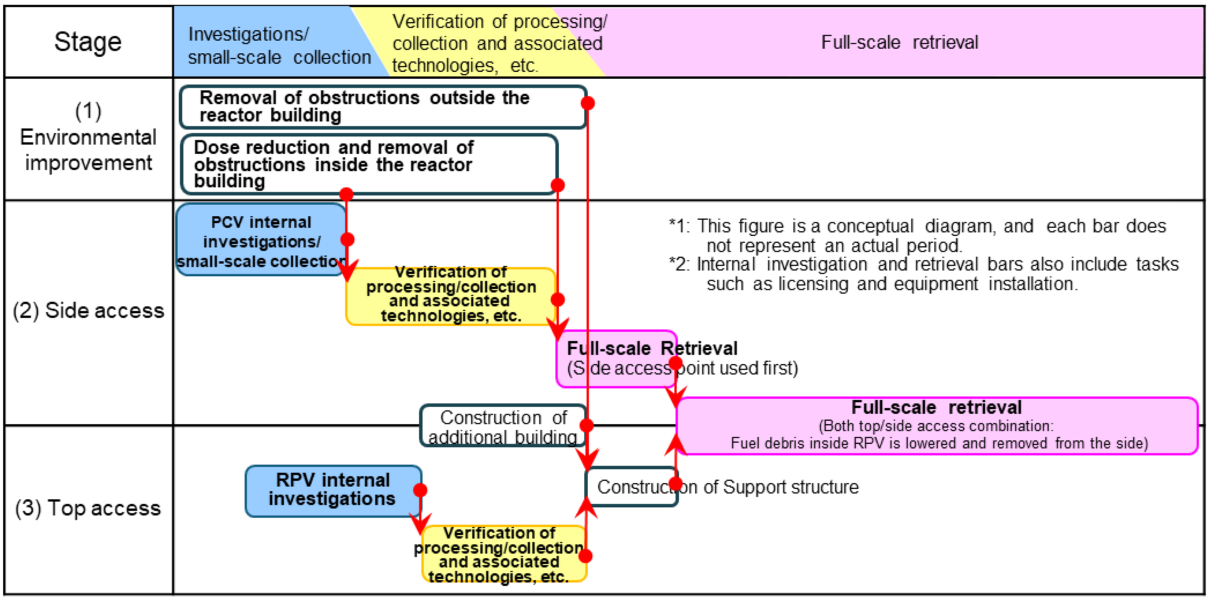


〔Source: TEPCO〕

Fig. 6 Conceptual drawing of the retrieval scenario steps ① through ③

(2) Outline of fuel debris retrieval scenario

The general picture of the fuel debris retrieval scenario begins with the “internal investigation and collection of a small quantity of fuel debris (small-scale collection) phase,” in which the accuracy of the design study for the retrieval method will be improved based on observations of the PCV and RPV internals through internal investigations, as well as the analysis information obtained by collecting a small quantity of fuel debris, such as compositions and properties. Next, in the “verification of processing, collection, and associated technologies phase,” data, such as data on dust dispersion and changes in water quality, will be obtained through the experimental processing (trial processing) of fuel debris, and incorporated it into the design of ancillary installations, such as gas and liquid systems (those that are primarily used to reduce radioactive materials contained in the gas and liquid in the PCV). Additionally, small-scale collection will continue to collect more data, such as data on the fuel debris properties, and incorporate it into the design of storage and other facilities. Then, the "full-scale retrieval phase" will be advanced using technology and installations that incorporates the above. A step-by-step approach is adopted, using the new information and experience obtained at each stage as input for the next step's design. It is essential to develop an appropriate environment in order to safely conduct work in each phase. For this reason, the necessary environmental improvements (e.g., radiation dose reduction and the removal of obstacles) will be implemented before the start of the on-site work. Moreover, the PCV and the RPV will be accessed from the top (operating floor) and side (the penetration on the first floor of the reactor building). Fuel debris will be retrieved through top or side-access, or by combining both methods (See Fig. 7). In the following example, retrieval will begin via side-access first. Once preparation for top-access is complete, the top and side-access methods will be combined for retrieval.



〔Source: TEPCO〕

Fig. 7 Implementation items and flow in the retrieval scenario

a. Outline of each phase of fuel debris retrieval via side-access

- Internal investigation and sampling phase

The objective is to acquire the information necessary for the verification of processing, collection, and associated technologies. Condition and environmental data inside and outside the pedestal as well as information on the distribution and quantity of the fuel debris in the PCV will be obtained through internal investigations. In addition, data on fuel debris properties and other related data will be obtained by collecting a small quantity of fuel debris samples. The inside of the pedestal in Unit 3 was investigated using an underwater ROV in July 2017. However, the platform inside the pedestal and the area outside the pedestal remain unexamined. For this reason, the following will be specifically performed: investigation of the upper part inside the pedestal using a drone through penetration X-53; investigation of the outside of the underground-level pedestal using an endoscope through penetration X-35; and investigation of the inside and outside of the pedestal using a drone through penetration X-6 and collection of a small quantity of fuel debris with remote control device. Key environmental improvements before this work is started include radiation dose reduction around penetration X-6 and the removal of obstacles to establish an access route.

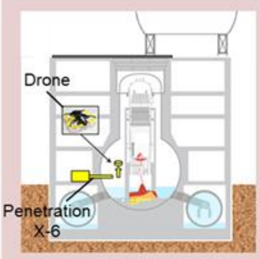
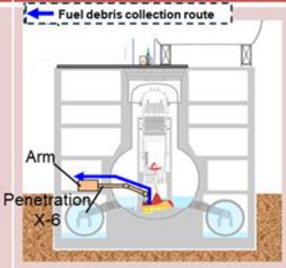
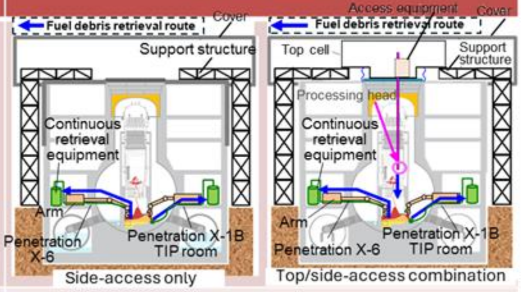
- Verification of processing, collection, and associated technologies phase

  The objective is to acquire the information necessary for full-scale retrieval. Data, such as data on obstacles inside the PCV and dust dispersion and changes in water quality during fuel debris processing will be obtained through trial processing and will primarily be incorporated into the design of gas and liquid systems as ancillary installations. Verification of whether the processed particulate fuel debris can be collected will be performed with a view to achieving continuous collection in the full-scale retrieval process. The access route from penetration X-6 to the pedestal through the CRD openings will be constructed, and then machining equipment will be attached to the end of the arm of the access device for trial processing. Key environmental improvements before this work is started include radiation dose reduction and the removal of obstacles on the west side of the first floor of the reactor building to establish an access route.

- Full-scale retrieval phase

  The objective is to complete fuel debris retrieval from inside and outside the pedestal. An access route (possible locations include X-1B and TIP (X-35) chamber) to inside the PCV other than via penetration X-6 will be established so that it can be used as an outlet for carrying out fuel debris retrieved from inside and outside the pedestal and as a return port for solid-liquid separated water. Obstacles will be removed in order to secure a retrieval route from the worker access opening on the pedestal, and fuel debris inside the PCV will be processed for continuous collection. First, fuel debris retrieval will begin using the side-access method, which has high accessibility. Once preparation for top-access is complete, the top and side-access methods will be combined for fuel debris retrieval. Key environmental improvements before this work is started include radiation dose reduction and the removal of obstacles around X-1B and the TIP chamber to establish an access route

Table 2 Overview of each stage of fuel debris retrieval via side-access

Stage	Internal investigation/ small-scale collection	Verification of processing ,collection and associated technologies, etc.	Full-scale retrieval
Schematic diagram			 Side-access only / Top/side-access combination
Purpose	• To obtain information necessary for verification of processing, collection and associated technologies	• To obtaining information necessary for full-scale retrieval	• To complete retrieval of fuel debris from inside and outside the pedestal
Details	• Obtain data on the condition and environment inside and outside the pedestal • Obtain information on the distribution and quantity of fuel debris in the PCV • Small-scale collection of fuel debris, etc.	• Confirm interfering objects and dust effects during fuel debris processing • Confirm data on the effects of water quality changes • Collect particulate fuel debris, etc.	• Construct PCV internal access routes other than penetration X-6 • Remove interfering objects to secure a route for transporting items from the pedestal worker opening • Process fuel debris inside PCV • Continuous collection of fuel debris inside PCV, etc.
Required environmental improvement	• Dose reduction and removal of interfering objects around penetration X-6	• Dose reduction and removal of interfering objects in the west part of the first floor of the R/B	• Dose reduction and removal of interfering objects around X-1B or TIP room

〔Source: TEPCO〕

b. Overview of each stage of fuel debris retrieval via top-access

- Internal investigation phase

The objective is to acquire the information necessary for the full-scale retrieval phase. After constructing an access route into the RPV, information on the condition of the existing reactor internals and radiation doses inside the RPV, as well as the distribution and quantity of the fuel debris in the core and its bottom, will be obtained through internal investigation. An internal investigation by accessing small openings via the top-access route allows for investigation of the core and its bottom, which is expected to be extended in the subsequent verification of processing, collection, and associated technologies phase. As for the RPV internal investigation, access through the dryer-separator pit (hereinafter referred to as the DSP), existing piping, or the bottom of the RPV is also concurrently being considered and the possible access route will be applied on site. In order to perform an internal investigation by accessing small openings via the top-access route as early as possible, the plan is to investigate via the access route created by drilling small openings from the operating floor, without removing the covers for spent fuel removal, existing shields, and shield plugs. For this investigation, the investigation device will be suspended from the toolbox installed on the operating floor to obtain information, such as the damage situation inside the RPV, images of the fuel debris distribution, and radiation doses.

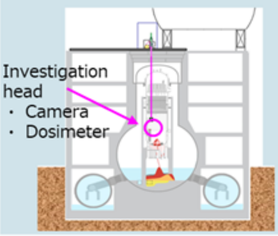
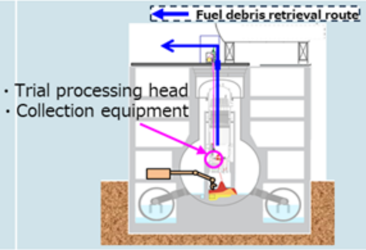
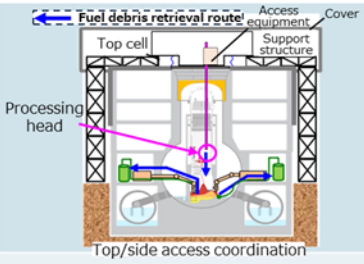
- Verification of processing, collection and associated technologies (including small-scale collection) phase

The objective is to acquire the information necessary for the full-scale retrieval phase. Reusing the above-mentioned access route for the internal investigation through the small openings via top access, a toolbox containing a processing/collection device, etc., will be installed on the operating floor. The processing device is suspended from the toolbox into the reactor to verify the effect of dust dispersion resulting from trial processing of fuel debris. In the same way, the collection device is suspended and lowered into the reactor, and a small quantity of particulate fuel debris is collected to obtain data, including property data.

- Full-scale retrieval phase

The objective is to complete retrieval of fuel debris in the RPV. In principle, a plan should be developed so that the route for collecting fuel debris does not pass through the operating floor, and the cell, retrieval and other equipment to be installed on the support structure for top access should not become too heavy. A secondary containment barrier building cover and a primary containment barrier upper cell will also be installed. In addition, small openings will also be used for full-scale retrieval. Several access routes will be established to process fuel debris throughout the core and its bottom. To carry fuel debris out of the RPV, a route should be secured to lower the fuel debris through the opening at the bottom of the RPV, where it is expected there is damage, to the bottom of the pedestal. The processing device to be installed inside the upper cell will be shaped like a mast (a pipe-like device with a machining head attached to the tip) suitable for passing through small openings and emergency recovery. As for the processing head, it is assumed that it will be, for example, a waterjet or laser based on the following aspects: the processing method can be unified regardless of the fuel debris properties (e.g., hardness, toughness, shape) ; processing can be performed remotely, and fuel debris can be processed into small pieces. The top and side-access methods will be combined to process and recover fuel debris once the retrieval equipment via top access is ready. Key environmental improvements required before this work is started include the removal of structures that would interfere with preparatory work for top access equipment.

Table 3 Overview of each stage of fuel debris retrieval via top-access

Stage	Internal investigation	Verification of processing, collection and associated technologies, etc.	Full-scale retrieval
Schematic diagram			
Purpose	• To obtain information required for full-scale retrieval stage	• To obtain information required for full-scale retrieval stage	• To complete retrieval of fuel debris from inside the RPV
Details	• Confirm the condition of preexisting structures inside the reactor • Construct access routes inside the RPV for investigation purposes • Obtain information on radiation doses • Acquire information on distribution and quantity of fuel debris in the core and at the bottom of the reactor, etc.	• Collect particulate fuel debris • Trial process fuel debris • Review the impact of dust during fuel debris processing, etc.	• Construct access routes inside the RPV for retrieval • Secure a route for transporting fuel debris from the RPV • Full-scale processing of fuel debris • Collect fuel debris (side access), etc.
Required environmental improvement	—	—	• Removal of structures that interfere with the installation of support structures for top-access

〔Source: TEPCO〕

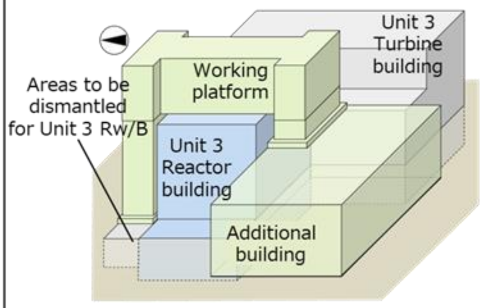
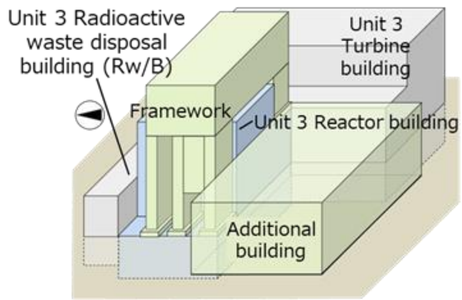
c. Outline of the additional building installation

For full-scale fuel debris retrieval, ancillary installations will be required, including gas systems, liquid systems, fuel debris/waste acceptance and pre-transfer treatment systems, as well as power systems and compressed air supply systems as utilities. Since not all of these installations can be located inside the reactor building due to space constraints, a building (hereinafter referred to as “the additional building”) will be constructed on the south side of the reactor building to store some of the installations mentioned above. The current plan is to install a gas system, a liquid system, and utilities in the additional building. The gas/liquid systems are designed based on the data obtained in the verification of processing, collection, and associated technologies phase in order to make them rational installations. (Since the additional building houses shared facilities for both top and side-access, it is shown at the boundary between top and side access in Fig. 7) Key environmental improvements required before this work is started include the removal of buildings and structures outside the reactor buildings that would interfere with the construction of the additional building.

d. Outline of the installation of a support structure for top access

A support structure for top access should account for the fact that the reactor buildings are damaged. As shown in Table 4, there are two proposed patterns for this support structure: a north-south working platform and an east-west framework. The north-south working platform plan is to install it across the reactor building in a north-south direction so that the ground can support the load of the support structure. This plan will impose little to no load on the reactor building. However, the challenge is that it requires the removal of the radioactive waste disposal building. Conversely, the east-west framework plan is to install it in an east-west direction so that the undamaged portion of the reactor building can support it, leading to reducing the volume of construction work. This plan will impose a load on the reactor building. Therefore, the challenge is that the weight of the cells and retrieval equipment to be installed on the framework are limited. Since it is difficult to determine which option is more suitable at this point, both will be discussed as the main proposals. Key environmental improvements required before this work is started include the dismantling and removal of the radioactive waste disposal building of Unit 3 and the removal of covers for spent fuel removal for the proposed south-north working platform, and the removal of covers, etc., for spent fuel removal for the proposed east-west framework.

Table 4 Case study examples of support structure for top-access

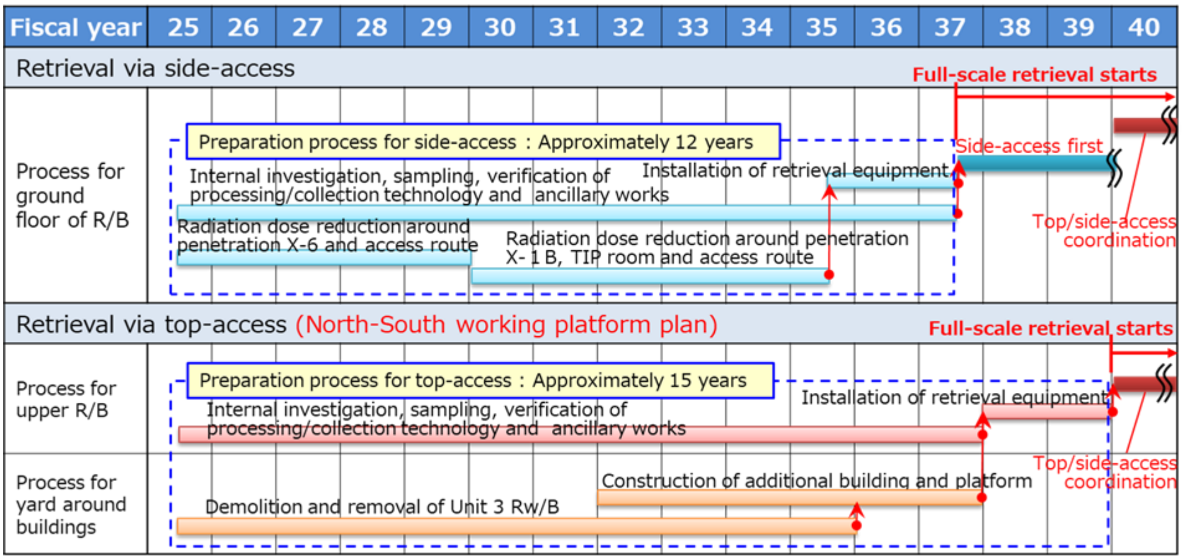
Examples of study	North-South working platform plan	East-West framework plan
Schematic diagram		
Expected main issues	■ Interference with Unit 3 radioactive waste disposal building (Rw/B))	■ Restrictions on loading equipment due to the load capacity of the reactor building

〔Source: TEPCO〕

（3） Processes up to the start of full-scale retrieval

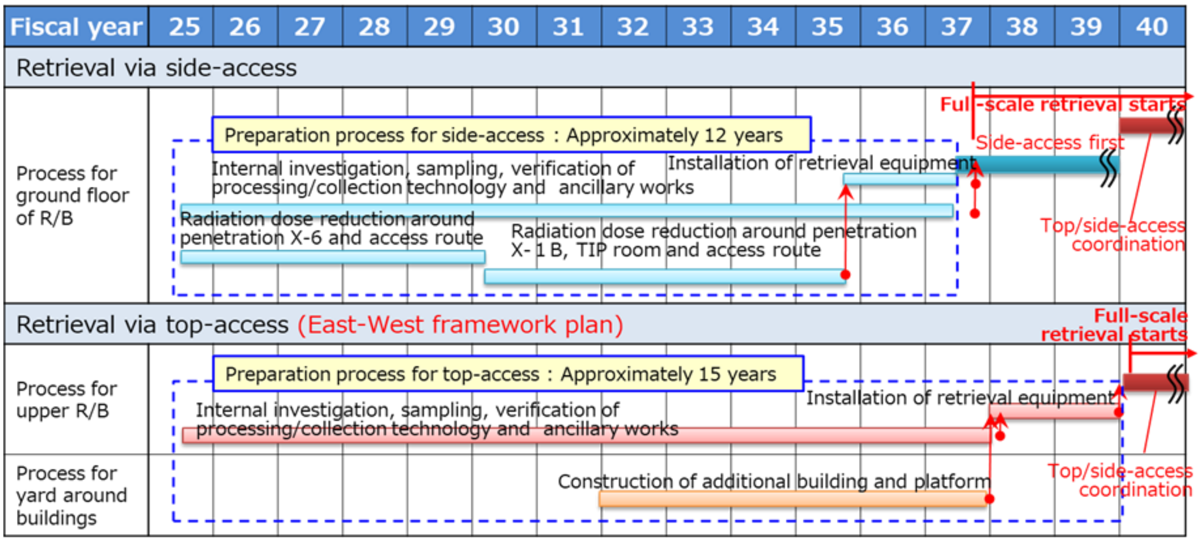
The current design study has examined the processes up to the start of full-scale retrieval (preparatory process) under certain assumptions. Since there is a large amount of uncertainty from the full-scale retrieval process onward, it is not included in this study. Moreover, as shown above, there are two proposed patterns for the support structure for the top-access method: a north-south working platform and an east-west framework. Therefore, the processes for both patterns were examined. Tables 5 and 6 show the process for both plans. Currently, it is estimated that preparing for side and top access methods for both the north-south working platform and the east-west framework plans will take 12 and 15 years (about 12 to 15 years), respectively. However, the result of this estimation assumes that progress is made as expected for matters that require further verification (those for which on-site information is insufficient, or further design study is required).

Table 5 Process if using the North-South working platform plan as support structure for top-access



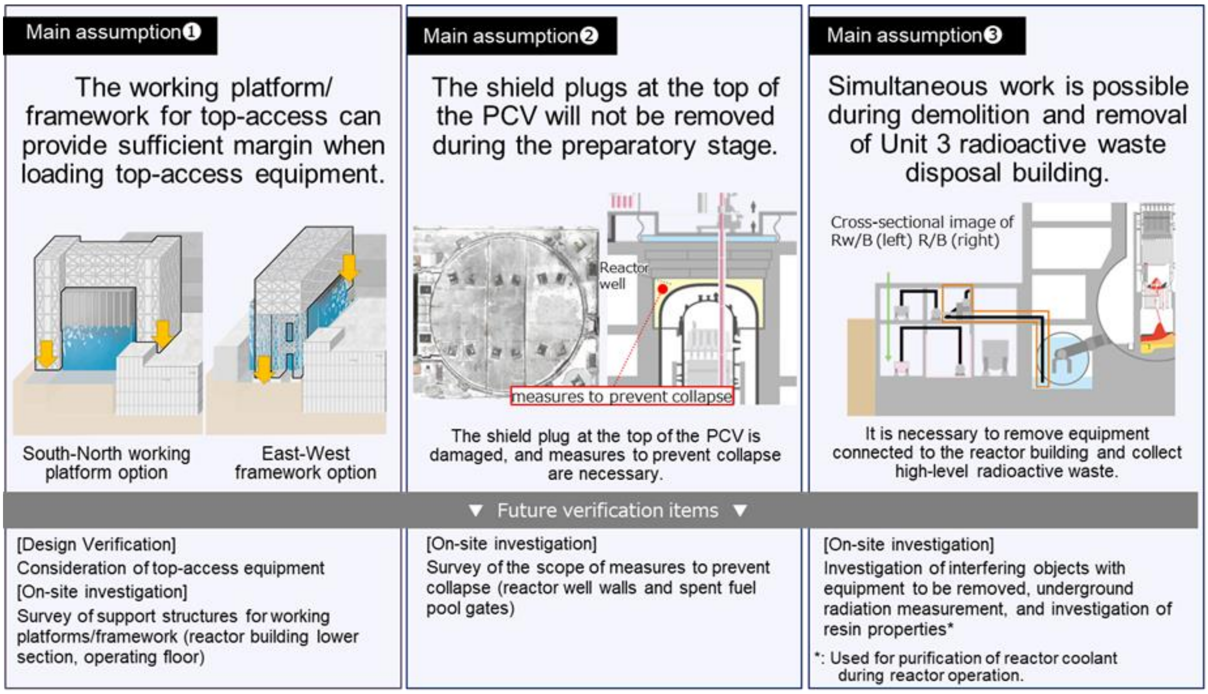
〔Source: TEPCO〕

Table 6 Process if using the East-West framework plan as support structure for top-access



〔Source: TEPCO〕

TEPCO will carry out on-site investigations and design verification over about one to two years to improve the accuracy of the design study regarding matters requiring additional verification for the north-south working platform plan and the east-west framework plan (the two plans for the support structure for the top access method). Fig. 8 lists the key assumptions and future verification items for matters requiring further validation. Primary assumption [1] is that the strength of the support will have a sufficient margin when the cell for top access, the retrieval equipment, etc., are loaded onto the support structure for the top access method. For further verification, a detailed examination of the top access equipment will be conducted and evaluate the strength margin by comparing the loads applied to the support structures with their allowable strength. In addition, the support (lean-to-roof of the reactor building and the operating floor) for the east-west framework plan will be investigated and evaluate the integrity of the support structures considering the extent of damage. Primary assumption [2] is that an access route through small openings can be constructed from the top of the shield plug without removing the shield plug from the upper part of the PCV by filling and solidifying the filler in the reactor well as a measure to prevent collapse. For further verification, the area where measures for preventing collapse to be implemented will be investigated (reactor well walls and gates of spent fuel pools) and evaluate the feasibility of filling and solidifying the reactor well and the effectiveness of measures to prevent collapse. Primary assumption [3] is that when dismantling and removing the radioactive waste disposal building of Unit 3, the removal of the installations connected to the reactor building (transfer of the stagnant water transfer equipment and removal of obstacles) can be carried out simultaneously with the recovery of high activity waste (high activity resins and other materials contained in the tanks to be removed). For further verification, investigation regarding interference to the equipment to be removed, a radiation dose survey on the basement floor, and investigation of the properties of high activity resin will be performed and evaluate the feasibility of concurrent operations by specifying the work area and procedures.



〔Source: TEPCO〕

Fig. 8 Key assumptions in the preparatory process and future verification issues

3.1.3.4.2 Future course of action

At the 16th meeting (July 23, 2025), the Sub-Committee for the Evaluation of Fuel Debris Retrieval Methods discussed Unit 3 Design Deliberation for Fuel Debris Retrieval Method, as summarized by TEPCO. The key points are as follows. Going forward, TEPCO will continue design studies in accordance with these points and will provide an outlook within one to two years. For this reason, the Sub-Committee will continue to exist for the time being to monitor the status of studies at TEPCO. NDF will check the status of TEPCO's design study and other activities as appropriate.

In addition, NDF will continue to follow-up with the Sub-Committee in order to obtain its advice and other inputs.

[Key points]

- If the opening is small, the access equipment will also be small, making the east-west framework plan realistic. However, the possibility of shifting to the north-south working platform plan in the course of the process should be considered.
- A more detailed examination is needed for the construction process of the proposed north-south working platform.
- Considering the possibility of shifting from the east-west framework plan to the north-south working platform plan and the need to reduce the risk of spent resin and sludge, all radioactive waste disposal buildings (radwaste buildings) in Units 1 through 4 should be dismantled and removed.
- For both plans, it is important to dismantle and remove the radioactive waste disposal buildings, conduct internal investigations, and reduce radiation doses in the reactor buildings.
- In addition to Unit 3, it is necessary to consider parallel work in the preparation process for Units 1 and 2.
- An outlook should be provided within one to two years of verifying the conditions assumed in this report and examining the emerging issues.

Due to high uncertainties, there should be no hesitation in conducting flexible re-examinations in future discussions.

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

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 problems regarding the accident at the Fukushima Daiichi Nuclear Power Station,” and has made reports on the progress of investigations and examinations based on the outcome of internal investigations and other findings. As of the 6th progress report in November 2022, the results of 38 examination cases had been presented, including all 10 cases classified as high-priority issues. TEPCO has been conducting estimations of the state of the RPVs and PCVs 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. Based on the increasing on-site findings, studies will begin on the remaining 14 issues. It is also important to further deepen understanding of the 38 issues for which certain evaluation results have been obtained so far, based on new on-site knowledge. The NRA has established the Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station (Accident Analysis Committee) and has been engaged in studies on accident analysis. The 2014 Interim Report reached certain conclusions on the issues on which the Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station (NAIIC) and the Investigation Committee on the Accident at the

Fukushima Nuclear Power Stations of Tokyo Electric Power Company (ICANPS) had different opinions. After that, based on the progress of the decommissioning work, the investigation and analysis items were organized into three fields, the activities of the Accident Analysis Committee were resumed in 2019. The latest 2024 interim summary reported on the current status of the investigation and analysis of the damage condition of the pedestal concrete revealed in the PCV internal investigation of Unit 1. The “trial retrieval” in Unit 2 is expected to provide useful information for these accident analysis activities.

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

The government has been supporting research and development on technically challenging issues related to the decommissioning of the Fukushima Daiichi NPS through the "Project of Decommissioning, Contaminated Water and Treated Water Management (hereinafter referred to as the " subsidized project for decommissioning"). 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 as described in Chapter 5, and 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 provides themes of ongoing research and development.

（1）Technology for RPV internal investigation

（2）Technology for work environmental improvement in the reactor buildings

（3）Development of analytical technology for radiation exposure dose assessment

（4）Technologies for containment, transfer and storage of fuel debris

（5）Impact assessment technique for dust dispersion i

（6）Fuel debris retrieval method

3.1.3.7 Issues in examining safeguards strategies

Since material accountancy and response to inspection 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 response to inspection 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 material accountancy and response to inspection to installations does not affect the decommissioning process.

3.2 Waste management

3.2.1 Targets

- The Solid Waste Storage Management Plan is developed and revised with regularly 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 this plan.
- 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 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 solid waste management processes as a whole from generation to recycling and disposal of solid waste should proceed for presenting appropriate measures. For that, first evaluate the individual waste streams, which are the flow of integrated measures for individual solid waste from characterization to recycling and disposal 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.

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.

< Key points of “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

- Evaluations of the flow of integrated measures from characterization to on-site recycling of metal and concrete with extremely low surface dose rates (hereinafter referred to as "recycling") and disposal (hereinafter referred to as “individual waste stream”) have been conducted for Individual solid wastes that are determined to be ready to consider, according to the progress of technological development in each field of solid waste. The results of these will be integrated in the future to propose appropriate measures as a whole for the specific management of solid waste.

- .As for new waste-related facilities, the operation of the 10th solid waste storage facility commenced in August 2024. The target completion period for the planned melting system has been revised from around FY2027 to 2029 to around FY2029 to 2031 due to the time required for its design study. The revised Storage Management Plan reflecting these changes was published in December 2024.
- In the Technical Prospects, the examples of foreign countries have been provided that have implemented the concept of the Waste Hierarchy (advocates that waste management is addressed in the following order of priority to the extent possible: (1) Waste Prevention, (2) Waste Minimization, (3) Re-use of Materials, (4) Recycling with (5) Disposal being the final measure. TEPCO has also been implementing initiatives by corresponding to the approach based on this concept. In addition, (1) Waste Prevention, (2) Waste Minimization and (3) Re-use of Materials are measures to reduce the generation of solid waste, and in the evaluation of individual waste streams, consideration will be conducted for (4) Recycling and (5) Disposal, which require management as solid waste.
- 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 demolition 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.

3.2.3 Key issues and technical strategies

In Phase 3, in order to determine the specifications of processed waste and their production methods, institutions concerned, led by NDF, are promoting technical studies on integrated measures from characterization to storage/management, processing, 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 study, including processing and disposal. Low-activity waste has the feature of enormous volume, and the limited number of analyses data obtained for high-activity waste due to the difficulties of sampling and analysis itself. 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. The plan is updated annually, and the plan formulated in March 2025 indicates that it is necessary to promote the expansion of analytical capabilities and the rationalization of analytical methods, mainly at the Laboratory-1 of Radioactive Material Analysis Research Facility, in order to realize the necessary analysis for the achievement of these objectives at an early stage. TEPCO and the JAEA continuously work together based on this plan 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 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 to promote steadily consolidating solid waste inside storage buildings. In addition, taking into account the views of the Committee on Supervision and Evaluation of the Specified Nuclear Facilities and the Technical Meeting on the Examination of the Implementation Plan of the Measures for the Specified Nuclear Facilities, regarding the practicality and rationality of storage of low-level concrete and other waste, it is important to examine the 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[7]”, 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, referring to advanced examples in other countries.

To enable a response to the increase in solid waste generated as the decommissioning progresses in the future, it is extremely important to consider developing decommissioning strategies for the Fukushima Daiichi NPS and measures to enhance their implementation. As part of this initiative, in cooperation with TEPCO, NDF will lead related organizations in studying waste streams based on their respective roles and materializing the entire solid waste management process (management of solid waste from generation to recycling and disposal). In addition, the study will be promoted to propose appropriate waste management in relation to the mid-to-long-term decommissioning plan.

3.2.3.3 Processing and disposal

Findings will be widely acquired by mutually feeding back research results in each field on individual waste streams, and the characteristics of individual waste stream option proposal with

[7] Refer to pp. 161 to 166 of Attachment 11. Prospects of processing/disposal method and technology related to its safety, Technical Strategic Plan 2021 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company, Nuclear Damage Compensation and Decommissioning Facilitation Corporation.

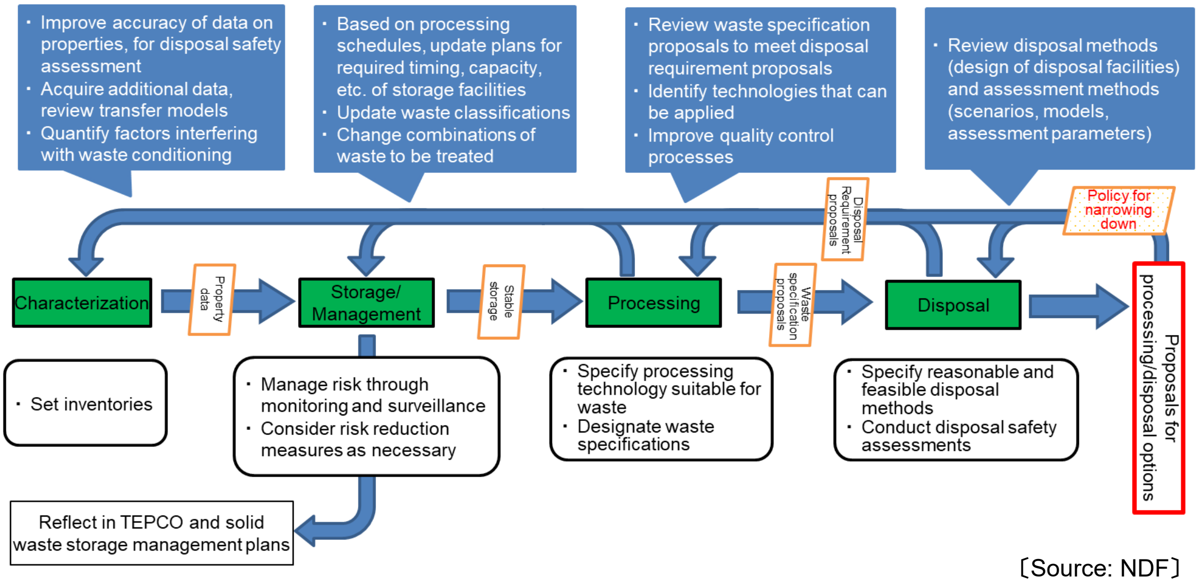
recognized safety and feasibility will be evaluated and the results will be accumulated. The individual waste stream option proposals will be integrated, and then evaluated and examined the results, and narrowed down to proceed with examinations to establish an appropriate waste stream. To this end, the R&D of processing and disposal technologies required for the series of studies, as shown in Fig. 9, will be continued.

Regarding 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 Committee on Supervision and Evaluation of the Specified Nuclear Facilities and the Technical Meeting on the Examination of the Implementation Plan of the Measures for the Specified Nuclear Facilities, requirements for selecting treatment technologies to be applied will be discussed with priority. As a matter of immediate consideration, studies 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 disposal concept option proposals 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 disposal concept option proposal, disposal concept option proposals covering all radioactive waste at the Fukushima Daiichi NPS will be considered. Then, contributions will be made to consider appropriate detailed waste management approaches as a whole in coordination with findings gained in areas of waste management other than disposal.

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



〔Source: NDF〕

Fig. 9 Procedure to reasonably select safe processing/disposal methods of solid waste

3.3 Contaminated water and treated water management

3.3.1 Targets

- 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 per day by the end of FY 2028 by preventing the inflow of rainwater and implementing local water sealing of buildings, while continuing the operation of the constructed water-level management system.
- Organize the relationship with the decommissioning processes including full-scale fuel debris retrieval beginning in the near future and contaminated water management, and promote examination of measures of contaminated water management for medium-and-long term prospects. Carry out periodic inspections and renewals of facilities systematically in order to maintain the effectiveness of contaminated water management into the future.
- Continue discharging ALPS-treated water safely and reliably and dismantle storage tanks in a planned manner in order to secure the site and other resources and steadily advance the entire decommissioning process.

3.3.2 Progress

- Due to multilayered contaminated water management, such as land-side impermeable walls and sub-drains, as well as prevention of rainwater infiltration by repairing damaged building roofs and facings on site, the amount of contaminated water generated in FY 2024 was approximately 70 m^3/day (approximately 80 m^3/day when corrected to rainfall in a normal year). The target of 100 m^3/day or less achieved in FY 2023 will be continued in FY 2024.
- In FY 2022, the milestone in the Mid-and-Long-term Roadmap, which was to reduce stagnant water in the reactor buildings to approximately half of the level at the end of 2020 between FY 2022 and FY 2024, was achieved. The collection of high radiation dose zeolite sandbags on the lowest floor is underway in order to expose the floors of the PMB and the HTI.
- As a countermeasure to reduce the risk associated with tsunamis, the sub-drain and other water catchment systems installed at 2.5 meters above sea level are being relocated to higher ground at 33.5 meters above sea level, and the tanks will gradually be switched to those on higher ground. For the waste sludge stored in the granulated solidification matter storage in the PMB, the design of the waste sludge transfer system and the radiation dose reduction in the PMB are in progress toward the transfer to higher ground.
- Since the discharge began in August 2023, ALPS-treated water into the sea has been proceeding smoothly as planned. The number of discharge to date is 15 times, the total discharged amount is approximately 120,000 m^3, and the amount of tritium that has been discharged is approximately 27 trillion becquerels. In September 2025, the IAEA published

Report 4: Fourth Review Mission to Japan after the Start of ALPS Treated Water Discharge and concluded that the Task Force confirmed that the equipment and facilities are installed and operated in a manner that is consistent with the Implementation Plan and the relevant international safety standards.

3.3.3 Key issues and technical strategies

3.3.3.1 Control of contaminated water generation

Fig. 10 shows an outline of the measures to control the amount of contaminated water generation. 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 at the end of FY2023. However, maintenance of sub-drains and land-side impermeable walls will continue 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 measures for local water sealing around Units 1 to 4 buildings, water sealing will be applied to the deep outer wall penetrations of the building and gaps between buildings to achieve the target “reduce the amount of contaminated water generated to about 50 to 70 m^3/day (end of FY 2028)”. Furthermore, local water sealing measures around buildings are expected to further reduce the already decreased groundwater inflow resulting from the commencement of operations for subdrains and the landside impermeable wall.

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.

After achieving the target of controlling the amount of contaminated water to about 50 to 70 m^3/day by the end of FY 2028, it will be necessary to continue efforts to reduce contaminated water generation, while ensuring consistency with the debris retrieval work in the study of fuel debris retrieval methods to be performed in parallel.

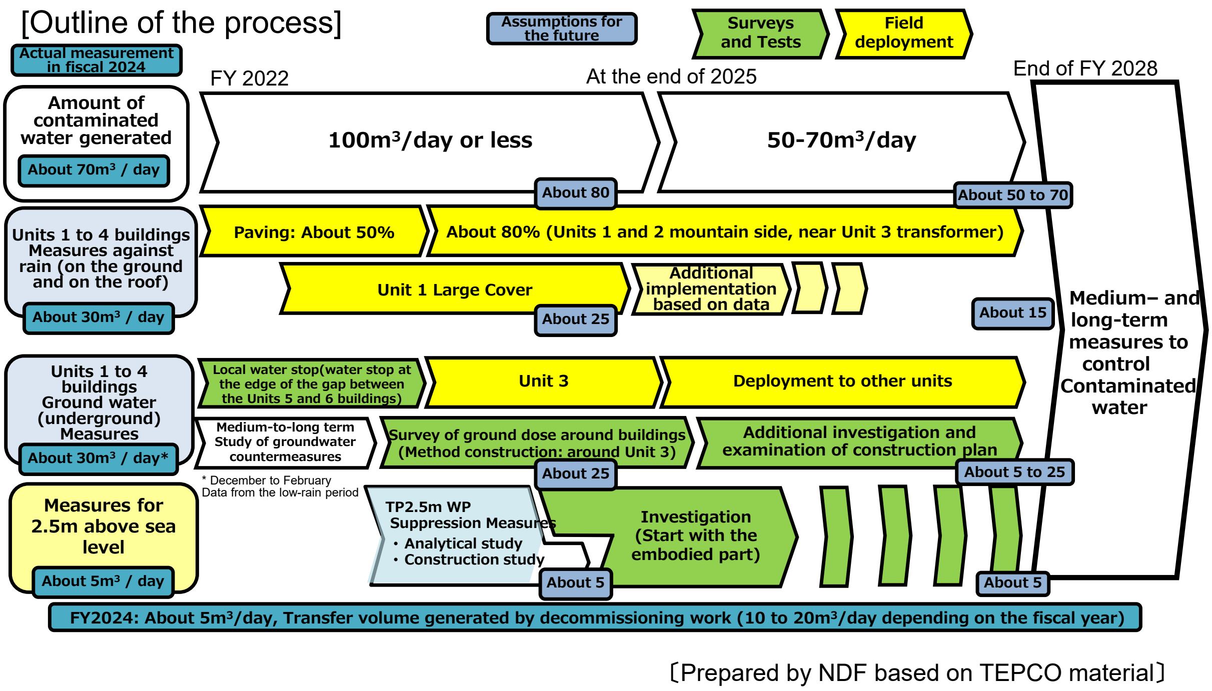


Fig. 10 Outline for measures to control the amount of contaminated water generation

3.3.3.2 Treatment of stagnant water in buildings

(1) Further reduction of stagnant water

High-radiation dose sludge containing cesium and α-ray emitting nuclides is present near the floor of the reactor building. Therefore, excessively lowering the water level of the building may lead to reduced water shielding effects, potentially 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 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 following measures are essential 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 the zeolite sandbags have high-radiation doses, the planned procedure is to collect them in a submerged environment using a robot for collection, and then transfer them to the aboveground floors using a robot for sealing them in containers, seal them into storage containers after demineralizing and dehydrating in the building, and then transfer them to temporary storage facilities. The collection work will be highly challenging as it requires collecting high radiation dose objects in basement floors with narrow passages through remote operation. Therefore, on-site work at the HTI began in March 2025, following improvements based on knowledge obtained through mock-up tests. Then, continuous work will start after the investigation of the implementation status. As for sealing the collected zeolite in containers, the full-scale mockup test showed that the design differential pressure was exceeded during filling and that the containers could not be filled with zeolite to full capacity. The cause is the refining of the zeolite particles during the transfer to the container, and the vertical transfer pump is being reexamined. Going forward, the actual work is planned to be started, following mock-up testing and the removal of existing equipment.

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

  Toward exposing the PMB and HTI floors, production of the temporary storage facilities for stagnant water, which have the functions of temporarily storing the stagnant water in the PMB and HTI buildings and separating sludge, is in progress. The operation check of the facilities is scheduled to begin in FY 2026. The plan is that the sludge separated and collected in the receiving tank is discharged for the time being to a limited area of the PMB basement floor and the water is collected through a floor funnel (drain outlet on the floor) to the temporary stagnant water storage facilities, thereby only storing the drained sludge. The facilities for directly collecting sludge from the receiving tank will be 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 on water treatment systems for the prevention of the spread of α-ray emitting nuclides and fuel debris retrieval

Previous analyses of stagnant water in buildings have confirmed that α-ray emitting nuclides primarily exist as granular particles. A total α-concentration of 10 Bq/L or below is currently maintained at the cesium sorption apparatus (SARRY/SARRY II) outlet, and the transfer of α-ray emitting nuclides to the downstream side has been suppressed. In the future, as fuel debris retrieval work starts and stagnant water in the PMB and HTI buildings decreases, more sludge settled at the bottom of the stagnant water in the building may be stirred up and mixed into the contaminated water, causing the total α-concentration at the water treatment system inlet to rise.

To address such concerns, preparatory work for installing filtering systems (α-nuclides removal equipment) downstream of the cesium sorption apparatus is underway.

During fuel debris retrieval, contaminated water containing a large amount of fine particles is generated by crushing, including cutting and other processes, and α-ray emitting 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-ray emitting 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, it is important to continue efforts to reduce the amount of contaminated water generated 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, TEPCO needs to continue to reliably operate the equipment in accordance with its own plan for the discharge of ALPS-treated water into the sea and communicate the status with high transparency and in a timely manner.

In the future, toward securing the site and other resources, it is necessary to develop an operational plan for the storage tanks so that the series of processes, such as secondary treatment of water under treatment, transfer of treated water between tanks, decontamination (if necessary) and dismantling of empty tanks, and storage of dismantled tanks, can proceed safely and rationally. In addition, in order to maintain stable transfer and discharge over the long term, it is important to improve the efficiency of the transfer and reception processes for treated water and ensure more reliable discharge. For example, it is expected that the receiving process will be shortened by using existing tanks as buffer tanks for receiving and by constructing a permanent transfer piping, pumps and filters to the measurement/confirmation facility (K4-ABC group tanks), leading to the materialization of the plan.

Regarding analysis of ALPS-treated water, in addition to the nuclides to be measured and evaluated (29 nuclides excluding tritium), TEPCO has also analyzed and evaluated (39) nuclides that have been voluntarily confirmed to be significantly absent by TEPCO, and disclosed the results. The analysis has been cross-checked with independent external organizations, including KAKEN CO., Ltd. and the JAEA Okuma Analysis and Research Center, and to date, no significant differences have been observed in the analysis results. 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

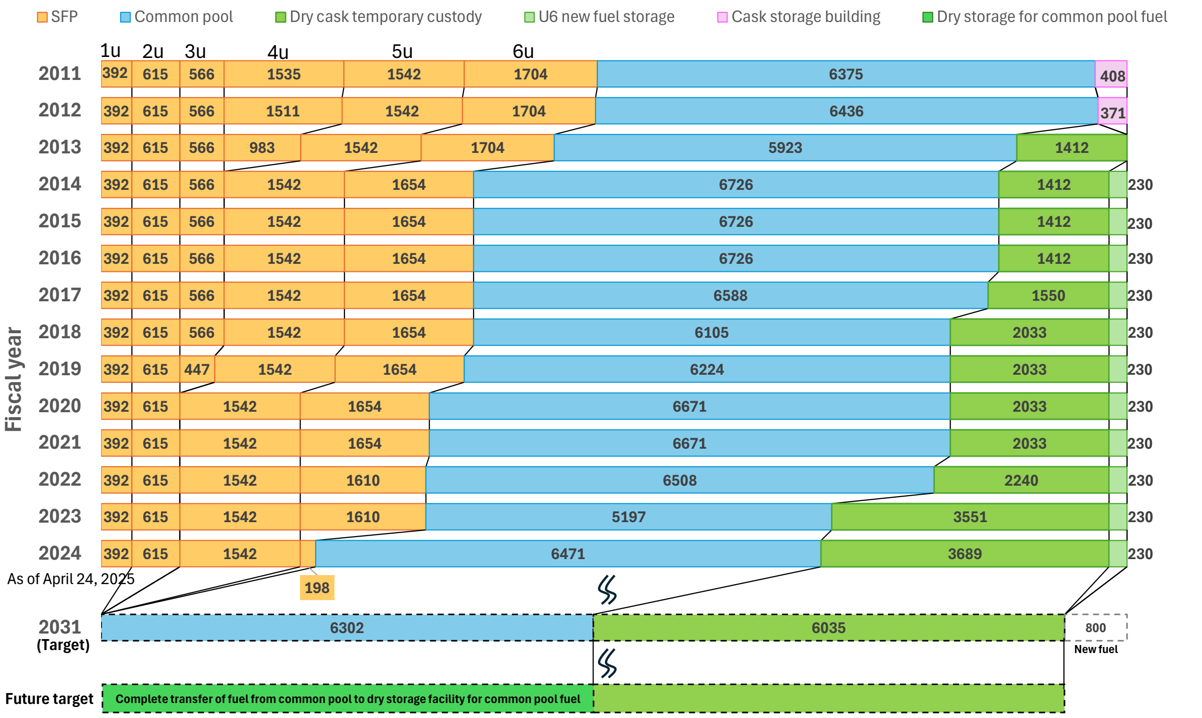
- To complete fuel removal from the spent fuel pools of all Units from 1 to 6 by the end of 2031.
- As the return of residents and reconstruction in the surrounding area gradually advances, to carry out a risk assessment and ensure safety, including preventing the dispersion of radioactive materials, 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 that were affected by seawater and rubble are removed from the SFPs and transferred to the Common Spent Fuel Storage Pool, etc., where they are 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
- The fuel in Units 1 to 4 that were affected by seawater and rubble are removed from the SFPs and transferred to the Common Spent Fuel Storage Pool, etc., where they are 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
- The spent fuel transferred from the SFPs in Units 1 to 6 to the Common Spent Fuel Storage Pool will be transferred to the “Dry Storage Facility to store fuel from the Common Spent Fuel Storage Pool”, which will be constructed in the future.
- The high radiation dose equipment will be transferred from the SFPs of Units 1 to 4. The pool water will be drained to eliminate the need for management of SFPs, and the load on the reactor building will be reduced to improve seismic resistance.
- To perform the evaluation of long-term integrity and the examination for processing for the removed fuel and to decide the future treatment and storage method.

3.4.2 Progress

Unit 1:
• The installation of the lower/upper frames and the removal of part of the outer steel frames were completed in preparation for installing the large cover. The movable roof for the large cover and the groundwork of the crane for rubble removal have been completed in the off-site yard. Preparation and installation of the box ring and movable roof are ongoing at Unit 1 reactor building. The large cover installation work is to be completed by the end of FY2025, and the target for the start of Unit 1 fuel removal is FY 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. Following the installation of openings to the reactor building and runway garters, the fuel handling machine was installed in May 2025 and its standalone operation testing started in August. Functional verification

of the fuel handling machine was completed at the factory in advance. Fuel removal is expected to start in the first half of FY 2026.
Units 3 and 4:
• In Unit 3, the transfer of all control rods to the site bunker was completed in December 2024. Following that, the transfer of high radiation dose equipment from Unit 4 SFP to the site bunker started in March 2025, and some control rods and channel boxes were transferred by the end of August. Subsequently, transfer of the filters of Unit 3 spent fuel pool started.
Units 5 and 6:
• The transfer of spent fuel from Unit 6 SFP to the Common Spent Fuel Storage Pool resumed in May 2024 and was completed in April 2025. After securing available space in the Common Spent Fuel Storage Pool, the transfer of spent fuel from Unit 5 SFP to the Common Spent Fuel Storage Pool started in July 2025. In addition, the implementation plan for adding dry casks at the Temporary Cask Custody Area was approved in August 2025, and storage in the expanded area is scheduled to begin in 2026..

Fig. 11 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.

〔Prepared by NDF based on TEPCO material〕

Fig. 11 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.

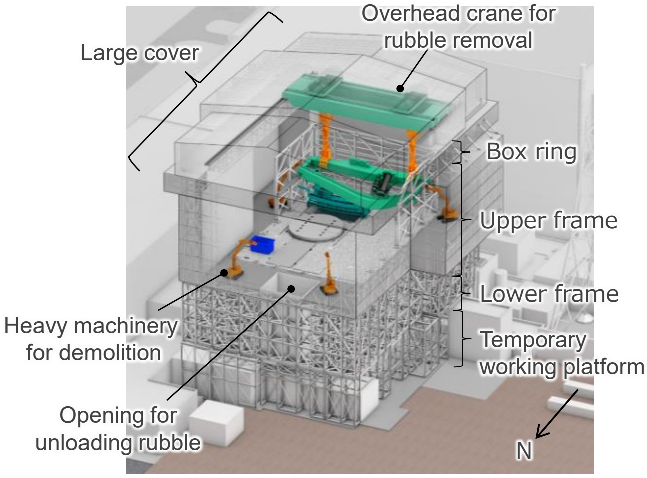
In promoting the project, it is essential to evaluate safety in association with work, to confirm that necessary and sufficient safety is ensured, and then to comprehensively consider the technical reliability, rationality, the promptness of the work schedule, the actual site applicability, the project 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
- Planning of potential risk scenarios and countermeasures
- Identifying points to consider, such as exposure of workers, from the operator's perspective

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. 12).



〔Source: TEPCO〕

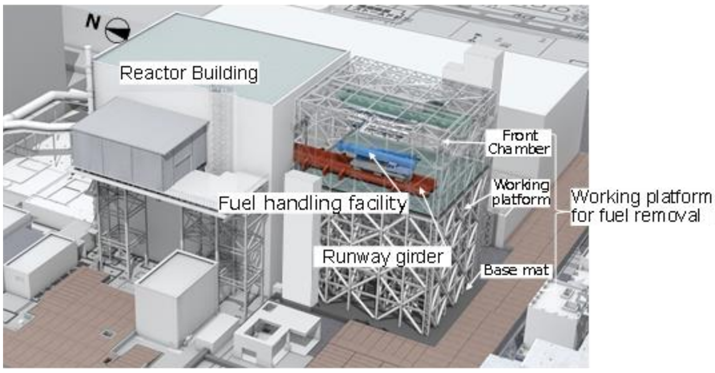
Fig. 12 Overview of the rubble removal from Unit 1 operating floor

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.

For 67 fuel assemblies with damaged cladding tubes, which have been stored in Unit 1 SFP since before the accident, efforts should be made to ensure verification of the post-accident condition and risk study associated with handling.

(2) Unit 2

The plan is to remove the fuel from the SFP through the opening on the south side of the operating floor by using a fuel handling machine composed of a boom-type crane system, which has never been used in nuclear facilities in Japan (Fig. 13). Since this is a new machine, it is imperative to identify risks related to operation and problems with the machine and take appropriate countermeasures in a reliable manner. In commissioning and training, people engaged in the fuel handling work should ensure that they proceed with the following actions while fully understanding the functions of the machine.



〔Source: TEPCO〕

Fig. 13 Fuel removal method in Unit 2 SFP

- Verification of the on-site operation procedure by actual workers
- Feedback to operation procedure, as necessary, based on the results

(3) Removing high-radiation dose equipment

Removing high-radiation dose equipment is underway in light of risk reduction in the event of pool water leakage. Once the high-radiation dose equipment is removed, it is possible to drain the pool water, leading to increased flexibility in using the operating floor and ensuring the smooth operation of subsequent fuel debris retrieval. It is also possible to exclude SFP-related systems from the management targets, resulting in simplified management. Draining the water can also reduce the load on the upper floors of the reactor building and contribute to improving the seismic resistance of the reactor building.

Due to the limited capacity of the existing site bunker (facility for storage of radioactive solid waste) for storing high radiation dose equipment, construction of a new site bunker is under consideration. Because there is a possibility of pool water leakage from the SFPs and the existing site bunkers, 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

Regardless of which dry storage facility is selected, the storage of damaged fuel and other materials within the pool remains an issue. The dry storage facilities to be applied should be determined based on the advantages and disadvantages of both the casks and the characteristics of the Fukushima Daiichi NPS, including fuel that has been affected by seawater and rubble. 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 Objectives 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. The objectives for each analyte are described below.

① The highest priority is given to handling fuel debris safely, appropriately storing/managing it. The collected fuel debris samples will be analyzed. The U-235/total uranium isotope ratio, uranium concentration range, structure and element distribution of the fuel debris, and other properties will be verified to incorporate the results into the studies on fuel debris handling, storage/ management.

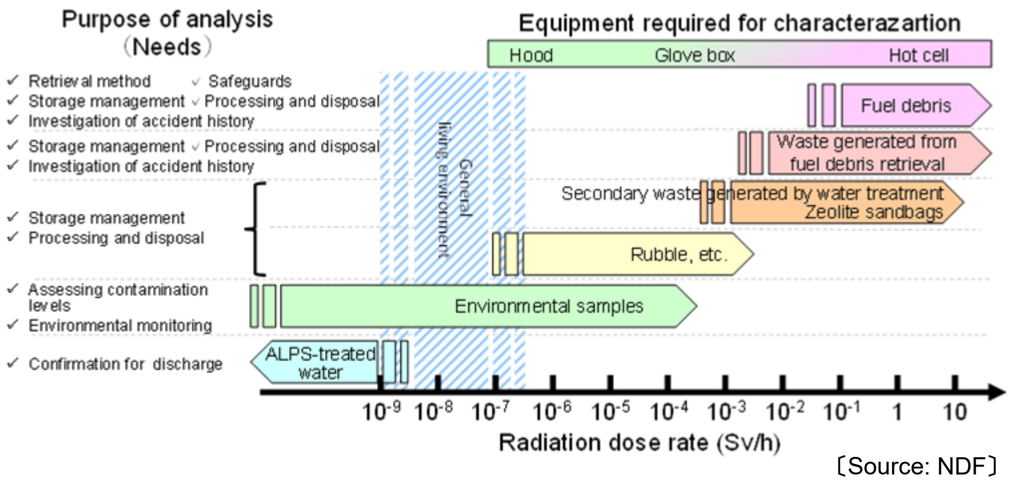
② With regard to solid waste, in order to contribute to the improvement of safety during storage and the examination of processing, recycling and disposal methods, assess the physical and chemical properties of solid waste and perform analysis to obtain data on nuclide composition, radioactivity concentration, etc.

③ Ensure in analysis that ALPS-treated water falls below the regulatory standard for safely discharging it into the sea. In addition, continue marine monitoring activities to confirm the condition of radioactive materials in the environment.

④ Promote the development of facilities for analysis and the training of analytical personnel, as well as the development of efficient radiological analysis/evaluation methods, in order to steadily proceed with a wide range of analyses focusing on the above points.

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. 14.



〔Source: NDF〕

Fig. 14 Relationship between the needs 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

It is necessary to flexibly respond to the expansion of analysis needs accompanying the progress of decommissioning work and to proceed with preparations in a planned manner so that decommissioning work is not delayed due to analysis.

The NRA has been reviewing the Target Map for Reducing Risks according to the progress of risk reduction activities. In 2024, the NRA set forth a goal to be achieved in FY 2033 (a decade later) for nuclide analysis, including water treatment waste, rubble, and building dismantling waste, as the priority areas for risk reduction.

TEPCO is strategically working on the characterization of wastes. In order to secure the necessary facility for analysis and human resources for this purpose, TEPCO has selected high-priority waste for analysis based on the progress of the analysis and the risks associated with storage and management, and developed the characterization policy and the analysis plan in 2023 according to the characteristics of each item of waste. In FY 2024, development of an analysis plan consistent with the procedure and schedule of the high-priority issues to be addressed for the time being, a revision of the analysis priority, and an update of the number of analyses based on the sampling situation were incorporated into the measures for mid-term Risk Reduction. In FY 2025, the analysis needs were updated along with the progress of examining the issues related to the measures for mid-term Risk Reduction, and the latest decommissioning work schedule was incorporated. In the future, the measures stated in the plan will be implemented, and the analysis plan will be reviewed continuously based on the progress and results of implementation.

（3） Development of radiological analysis/evaluation methods

Because solid waste is diverse and large in quantity, it is necessary to proceed with efficient characterization. For this reason, the subsidized project for decommissioning is making efforts to develop analytical methods that can obtain data easily and quickly; develop measurement and analytical methods that can handle various forms of samples and difficult-to-measure nuclides; standardize analytical methods accelerated by streamlining and automating sample pretreatment; and establish characterization methods with limited analytical data.

As for the development of the standard analytical method, its applicability to the actual samples was verified at Laboratory 1 of JAEA's Radioactive Material Analysis and Research Facility. Methods for measuring and analyzing difficult-to-measure nuclides, which are important for the safety assessment of disposal, are under development. Analysis results obtained through the established measurement and analysis methods will be incorporated into the future analysis plan for characterization.

（4） Securing facilities for analysis

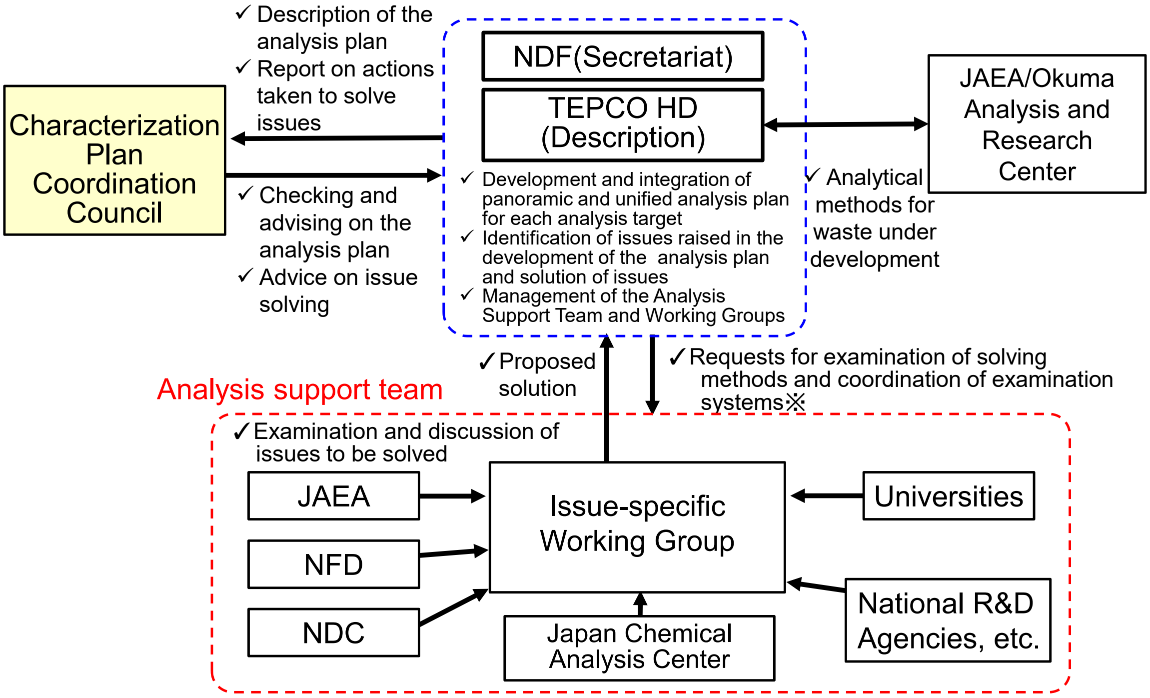
The JAEA's Radioactive Material Analysis and Research Facility (Laboratories 1 and 2) has the advantage that off-site transportation is not required because the facility is defined as facilities in the peripheral monitoring area of Fukushima Daiichi NPS. Leveraging these facilities, it is effective to promptly identify the basic physical properties and incorporate them into safety assessment and work procedures. 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 needed. In doing these, it is important 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, processing, recycling and 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. 15). 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 consists 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 Characterization Plan Coordination Council took place in August 2023 and its second meeting in October 2024. To give an example of discussions at the meeting, discussions were held regarding proficiency tests to enhance the reliability of analytical data. In response, NDF is considering a method of preparing a standard sample for proficiency tests using a mock concrete rubble sample from solid waste.

It was determined that a “working group (WG) to address issues” has been established in the Analysis Support Team to evaluate and review fuel debris analysis. This WG intends to incorporate the considerations gained through broad, in-depth discussions across sectors into relevant fields, such as accident progression analysis, safe storage/management, and processing, recycling and disposal, in relation to the analysis results obtained to date and those to be obtained in the future. From the viewpoint of the continuity of discussions, members of the WG are to consist mainly of young or middle-ranked researchers, engineers, etc., who will be able to participate in discussions over the medium-to long term and TEPCO will attend the WG as an observer in a bid to develop its analysts and analysis engineers through discussions.



NFD: Nippon Nuclear Fuel Development Co., LTD
NDC: MHI Nuclear Development Corporation

〔Source: NDF〕

Fig. 15 Role of the Characterization Coordination Council and the 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.

In the analysis of solid waste, it is necessary to aim for the improvement of domestic and international reliability of analysis results, with a view to the future recycling and disposal of solid waste. Conducting proficiency tests conforming to ISO/IEC 17043 for facilities involved in waste analysis is an effective means of improving analytical skills and reliability. It is important that the radioisotopes contained in the mock samples for proficiency tests are uniformly distributed to prevent differences in analytical values between analytical institutions. To this end, NDF was studying methods for preparing simulated concrete rubble samples in FY2024.

In performing 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 applications 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 technological development for automatic quantification of these materials is being made at the same time.

While it is important to increase the number of samples 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

Analysis of fuel debris has begun following its trial retrieval. In order to respond to the increased size and quantity of samples in the future, 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.

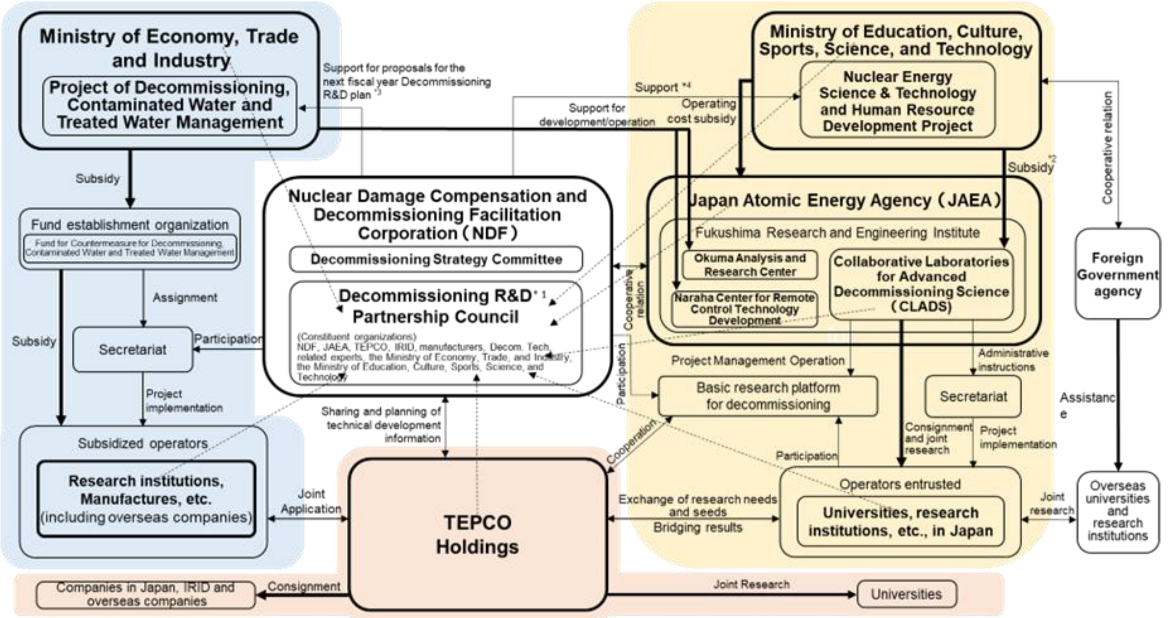
5. Efforts to facilitate research and development for decommissioning of the Fukushima Daiichi NPS

5.1 Significance and the current status of research and development

In Phase 3 of the Mid-and-Long-term Roadmap, the plan is to gradually expand the scale of fuel debris retrieval. Therefore, it is necessary to further advance research and development, in consideration of the on-site application, to prepare for the “further expansion of the retrieval scale”. For applied 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 subsidized project for decommissioning 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”). NDF is engaged in R&D medium-and-long-term planning, the next fiscal year’s decommissioning R&D planning, supporting the World Intelligence Project, and enhancing collaboration between basic/fundamental research and practical application research through the Decommissioning R&D Partnership Council (Fig. 16).

Given that the progress of investigation inside the reactors has clarified on-site needs in decommissioning and that TEPCO has begun engineering work for full scale fuel debris retrieval, in FY2023, the leading players in the subsidized project for decommissioning shifted to a new R&D framework where researching institutions and private-sector entities such as Toso Mirai Technology Company (hereinafter referred to as “Decom.Tech”) are the key implementers. In addition to project management of the business required as a joint venture partner, TEPCO should take responsibility for conducting research and development with practical application in mind through project management that takes into consideration the utilization of R&D results. Furthermore, it is necessary to further promote the acceleration of engineering based on retrieval method scenarios and the proactive provision of R&D needs. Relevant organizations are required to discuss issues, including basic/ fundamental research, which arise from TEPCO's engineering needs, and to further encourage coordination between R&D, basic/fundamental research, and practical application research for fuel debris retrieval in the subsidized project for decommissioning, the World Intelligence Project, and TEPCO’s technical development.

NDF will continue to exchange information on the status of R&D and human resource development at the Fukushima Institute for Research, Education and Innovation (F-REI).



*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.

〔Source: NDF〕

Fig. 16 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 and updating the R&D medium-and-long-term plan for the decommissioning of the Fukushima Daiichi NPS every fiscal year since FY 2020. The plan outlines the overall research and development for decommissioning for about the next 10 years, so that R&D activities for decommissioning of the Fukushima Daiichi NPS can be promoted comprehensively, systematically, and efficiently. Since FY 2023, TEPCO, Decom.Tech, JAEA, and NDF have initiated activities to share issues in R&D for the decommissioning (hereinafter referred to as “Four Party Cooperative Activities”) and have been incorporating the study results into the R&D medium-and-long-term plan. In FY 2024, a special task was established as part of the Four Party Cooperative Activities for discussing issues based on the recommendations of the Sub-Committee. Going forward, specific studies on R&D tasks, including basic/fundamental research based on the needs arising from discussion toward “further expansion of the retrieval scale”, will be conducted through the Four Party Cooperative Activities. The R&D tasks will be incorporated into the R&D medium-and-long-term plan as necessary.

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.

NDF is working to smoothly and steadily facilitate the subsidized project for decommissioning by (1) formulating the next fiscal year's decommissioning R&D plan for the next two years; (2) securing R&D planning proposal function utilizing Requests for Information (hereinafter referred to as "RFI") to broadly solicit issues to be addressed for decommissioning; and (3) strengthening the function of ensuring the practical applicability of R&D results through project reviews. In addition, NDF will consolidate technical information from a wide range of sources, including large or venture companies in Japan and overseas, and will work to further strengthen the collaboration between basic/fundamental research and applied/practical research. As part of the initiatives for FY2025, the R&D tasks specified in the special task of the Four Party Cooperative Activities were incorporated into the Decommissioning R&D Plan in response to the Sub-Committee's recommendations. The RFIs explained the current challenges in detail in each project and provided the necessary key technologies to attract new participants and for information providers.

Furthermore, as part of the collaboration between basic/fundamental research and applied practical research, some of the results of the World Intelligence Project have been applied to the Decommissioning subsidized project. The further collaboration between the two is important for bringing about breakthroughs to decommissioning issues and enhancing safety more efficiently and effectively. Therefore, NDF will further strengthen collaboration to solve decommissioning issues by summarizing collaboration issues and examining countermeasures.

The challenge lies in preventing the outcome of the development that has been conducted through the Decommissioning subsidized project from becoming fragmented, making the outcome widely available to the public, and establishing a structure that enables those in the nuclear sector as well as engineers and researchers in the non-nuclear sector to utilize the outcomes of R&D effectively. Therefore, it is necessary to promote archiving and public relations that cover effective information disclosure, as well as a mechanism for utilizing decommissioning technology.

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

The Ministry of Education, Culture, Sports, Science and Technology has promoted basic/fundamental research and human resource development for universities and researching institutions, which will contribute to solving decommissioning issues at the Fukushima Daiichi NPS, through the World Intelligence Project at the Collaborative Laboratories for Advanced Decommissioning Science, Fukushima Decommissioning Safety Engineering Research Institute, JAEA (hereinafter referred to as "JAEA/CLADS").

To deepen the matching between needs and seeds and to promote collaboration in R&D for decommissioning from basic/fundamental research to applied/practical application research, there have been efforts such as workshop activities for matching needs and seeds in the World Intelligence Project.

In order to make the long-term decommissioning of the Fukushima Daiichi NPS proceed steadier, it is essential to develop and utilize fundamental technologies and collect basic data, develop and utilize 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

The decommissioning of the Fukushima Daiichi NPS is an unprecedented project in the world and requires considerable management resources (workforce, funds, and time). To successfully accomplish this project, it is essential that TEPCO demonstrates a strong commitment to treating the decommissioning of the Fukushima Daiichi NPS as its own responsible project, all in a company-wide efforts. Additionally, the government must provide support to ensure that the decommissioning is carried out safely and reliably.

In FY 2020, TEPCO announced its “Mid-and-Long-term Decommissioning Action Plan” as its ten-year decommissioning plan. Although the decommissioning work has generally been proceeding as planned, delays have occurred in some projects with high uncertainty. Therefore, it is also important to establish the decommissioning process that takes into account technical and project management risks, and to prioritize the tasks in the Mid-and-Long-term Decommissioning Action Plan and level the workload in order to make prolonged decommissioning sustainable.

Moreover, TEPCO must continue to deliberate and evolve the capabilities that should have as an owner[8], the ideal form of its strategic organization, and relationships with its partner companies to adapt to Phase 3 of the Mid-and-Long-term Roadmap in stages. In order for TEPCO to responsibly complete the decommissioning of the Fukushima Daiichi NPS, there are certain aspects that TEPCO cannot handle on its own. From now on, TEPCO should steer toward sharing its vision with its partner companies, building relationships of trust by working together, solving issues by gathering wisdom as equal partners (One Team), and improving the level of safety and quality.

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. Project-based organization management has mostly been established. Having entered Phase 3, the

[8] An owner here has three positions: a party responsible for disaster occurrence, a specified nuclear facility licensee, and a facility owner. TEPCO is executing the decommissioning project from these three positions. (A project executor of decommissioning)

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 further strengthen the management framework in cooperation with each other towards the goal to be achieved. Examples of main initiatives undertaken by TEPCO to date include reorganization to appropriately address changes in the site situation and social and local needs, e.g., establishing the “Office for the Promotion of Remote Technology Utilization (provisional name)”, in preparation for the growing need for operations using remote-controlled devices, enhancing risk management, and preparing a proactive plan (Mid-and-Long-term Decommissioning Action Plan).

6.1.1.2 Capability an owner should possess

TEPCO, as an operator, is required to have “project management capability,” “engineering based on safety and operators’ perspectives,” and the “capability to refine the overall decommissioning strategy in view of the peculiarities of the Fukushima Daiichi NPS and promote the 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

TEPCO needs to continue instilling in everyone working at the Fukushima Daiichi NPS that safety is the top priority. 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. TEPCO is working to introduce a structure for strengthening this investigation capability 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 is becoming difficult for TEPCO to proceed with work only through one-way purchasing (buying) from clients to contractors. 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 belongs 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. Currently consideration for integration is being promoted. 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 Consideration of contracting arrangement for long-term decommissioning projects

TEPCO established the Procurement Department in July 2024 in order to further strengthen its procurement capabilities and optimize its procurement functions by integrating procurement organizations and providing unified responses. One of the important strategic initiatives of the Procurement Department is participation in the upstream side of large-scale projects. The Procurement Department has started an initiative in which it is involved from the conceptual stage of a project and works together with the Technical Department to determine the procurement policy (EPC[9] bulk/separate order, supplier selection, contact system, specification standardization, etc.).

Now that Phase 3 of the Mid-and-Long-term Roadmap has started, the number of large-scale, long-term projects with high uncertainties[10], such as further expansion of the retrieval scale of fuel debris, is expected to increase. Therefore, the important factor to smooth project execution is introducing the collaborative contract method (hereinafter referred to as “Cooperative Agreement”), which encourages cooperative project execution for risk reduction based on the understanding and sharing of the project mission and the risk factors by both the ordering party and the contractor.

In FY 2024, NDF conducted a case study on cooperative agreements used overseas and overseas projects that adopt them. Based on the findings of the study, NDF and TEPCO started considering introducing cooperative agreements for decommissioning the Fukushima Daiichi NPS.

As the decommissioning progresses, the need for maintenance work will increase due to management of new facilities for fuel debris retrieval and aging risk of existing facilities. Therefore, the weight of operation and maintenance work is expected to increase in the long term. TEPCO has, together with its contractors who play a central role in operation and maintenance, examined the ideal form of sustainable and equalized operation and maintenance contracts to allow contractors to develop and secure human resources over the long term without anxiety. In FY 2025, TEPCO began cooperative initiatives in concluding contracts, including introducing a system to bundle order units or extend the ordering period, as a pilot system.

6.1.2.2 Consideration of ideal on-site management in coordination with partner companies[11]

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.

NDF believes that the background factor to the four incidents that occurred after October 2023, including body contamination during the cleansing of the additionally installed ALPS pipes, is the difficulty of on-site management in the multilayered contract structure. A multilayered contract structure is one in which a primary contractor receives an order for a commissioned project and then recommissions it to a subcontractor (concludes a subcontract). The multilayered contract structure has disadvantages, including unclear responsibilities, worsening working conditions for subcontractors and lower-tier contractors, and a lack of human development. However, it has advantages, such as improving the quality of construction by utilizing companies with expertise and know-how in specific fields, and increasing the chance of receiving orders.

[9] Engineering (design), Procurement (equipment procurement (product manufacturing)), Construction (installation)
[10] “Uncertainty” here refers to a state in which it is difficult to predict future events and outcomes.
[11] Among TEPCO's client firms, those engaged in on-site work at the Fukushima Daiichi NPS are called "partner companies”

To improve the level of safety and quality on site in a multilayered contract structure, the key is for both TEPCO and its partner companies to recognize that all workers are peers (partners), develop equal relationships, and build a team that can take action with a common goal. TEPCO should not intervene in the details of contracts between relevant parties. However, it must grasp an understand the actual situation of the partner companies working at Fukushima Daiichi NPS (e.g., which contractors are undertaking what work, whether the right contractor system is in place for the right job, and what strengths each contractor has). Then, TEPCO should aim at creating a system for “performing work as a team” in which all companies at all levels involved in a single task function under the same objective and TEPCO’s comprehensive responsibility.

TEPCO has been working step-by-step to “strengthen the operator/worker-first system and education” and “improve operator/worker-first facilities and the environment” in response to the four incidents that have occurred since October 2023, such as body contamination during cleaning of the additional ALPS piping. Based on the results of these efforts, TEPCO is considering expanding the scope of maintenance work for the new ALPS in the future and other operations with high exposure and safety risks, other than water treatment systems. One specific initiative is the establishment of a " one-team approach " for facility operation and maintenance. Starting in FY2025, TEPCO, as the orderer, and its partner companies, as contractors, form teams to collaborate on maintenance work for ALPS (including sorption material backwashing, sorption material replacement, cross-flow filter cleaning, etc.) as a trial project.

TEPCO's one-team approach is an important initiative for reducing human error, ensuring workplace safety, cultivating a spirit of collaboration between parties placing and receiving orders, instilling the awareness that each individual member is responsible for the plant, and increasing safety awareness. NDF will continue to verify that these activities are progressing steadily and that the necessary budget has been secured.

6.1.3 Securing human resources who engage in decommissioning, fostering the next generation to handle 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 and reorganization of the Fukushima Daini NPS and its headquarter function into the Fukushima Daiichi Decontamination and Decommissioning Engineering Company, 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 and the JAEA are 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. Specific initiatives for human resource development include the Decommissioning research program based on development of research human resources of the World Intelligence Project in Phase 3[12] that was started in FY2024 and the decommissioning creative robot competition for technical college students.

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.

[12] 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 JAEA/CLADS knowledge and experience of various fields accumulated in universities.

6.2 Strengthening international cooperation

6.2.1 Significance and the current status of international cooperation

Amid various developments around the world regarding decommissioning measures, such as recycling of nuclear reactors against the backdrop of efforts to secure power supplies for the advances in AI and other technologies, efficiency improvements of the US government agencies including the US Department of Energy, progress in the decommissioning of the Chernobyl Nuclear Power Plant Unit 4 (ChNPP-4) in Ukraine and the impact of the conflict, it is essential to leverage the knowledge and experience gained from previous decommissioning activities at overseas nuclear-related facilities (hereinafter referred to as "legacy sites") in order to steadily advance the decommissioning of the Fukushima Daiichi NPS, which involves highly challenging engineering issues. The Mid-and-Long-term Roadmap has advanced to Phase 3 and, it is necessary to establish measures related to decommissioning, based on the progress of decommissioning, R&D and other related activities,while gradually expanding the scale of fuel debris retrieval. In light of this background, through the medium- to long-term decommissioning efforts at overseas sites similar to those in Japan,it is essential to grasp technological trends that could contribute to facilitating progress of decommissioning work at the Fukushima Daiichi NPS, to promote technical cooperation to apply such technologies to the decommissioning of the Fukushima Daiichi NPS as necessary, and to gain experiences and lessons on precedents, regional engagement, and decision-making processes when establishing matters related to decommissioning measures. As a means to achieve this, for example, it is beneficial to build bilateral cooperative relationships that align with each country's circumstances, as well as to participate in meetings of specialized nuclear agencies such as the IAEA and OECD/NEA, and to engage in exchanges with overseas experts.

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 promoting international collaboration 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 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 collecting and utilizing 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”) with the participation of international organizations related to nuclear energy, such as the IAEA and OECD/NEA, as well as experts from various countries with expertise in nuclear energy. The forum aims to share overseas examples of decommissioning and insights on how to proceed with decommissioning smoothly, as well as to provide ongoing information to the international community regarding the current status and issues of the decommissioning of the Fukushima Daiichi NPS.

Fig. 17 The 9th international Forum on the Decommissioning of the Fukushima Daiichi NPS (August 2025)

〔Source: NDF〕

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, including the technical knowledge, operational know-how and other lessons learned from decommissioning of overseas legacy sites. Based on these, the decommissioning is undertaken with the following three strategies taken into consideration.

a. 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.

b. Utilization of a broad range of technological information that contributes to decommissioning

The decommissioning of the Fukushima Daiichi NPS is a process of solving unexplored engineering problems by combining knowledge from various fields, not limited to the nuclear field, and it could become a key opportunity for the creation of innovation. Technical information will continue to be collected in order to explore the application of more technologies to decommission and to obtain the cooperation of countries that do not use nuclear technology and experts from non-nuclear industries.

c. Continuation of mutually beneficial relationship

Ensuring mutually beneficial relationships will be continued while being conscious of returning the various information, expertise and results relating accident causes and decommissioning 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 the Fukushima Daiichi NPS and to limit the risk of confrontational structures to the implementation of decommissioning to the extent possible.

International opinion could considerably impact the progress and success of decommissioning. Therefore, it is important to strategically consider and implement international cooperation in order to prevent misperceptions about the decommissioning of the Fukushima Daiichi NPS from spreading overseas. The strategy for maintaining and developing the understanding and interest of the international community and the cooperative relationship should be divided into the approach to overseas experts and the approach to the overseas general public.

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. Therefore, 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. Moreover, the participation of local companies in the decommissioning project will revitalize the decommissioning-related industries in the region, which will be important pillars in contributing to Fukushima's reconstruction. Approximately 3,600 to 4,900 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, and it is important to continue contributing to the community over the long term from the perspective of local employment. 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 major 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 Technology Co. Ltd. to conduct basic design of systems and equipment with necessary research and development required for "further expansion of the retrieval scale", and Tousou Mirai Manufacturing Corporation to manufacture various core products necessary for decommissioning, including spent fuel cask, were established in October 2022.

Tousou Mirai Manufacturing plans to begin manufacturing and supplying metal casks for use at the Fukushima Daini NPS as its first step in the production of decommissioning-related products. The company is conducting recruitment activities based in the Hama-dori region and within the prefecture, collaborating with local companies to construct the Hama-dori Plant (Naraha Town) (completion scheduled for FY2027), and holding information sessions for companies in the prefecture to establish manufacturing supply chains, including component processing and equipment production. These efforts are being promoted in collaboration with relevant institutions to advance preparations for the full-scale commencement of manufacturing.

6.3.2 Key issues and strategies

（1） Communication issues and strategies

Since misunderstandings, concerns, and reputational damages on the decommissioning could hinder the reconstruction of Fukushima, TEPCO must continue its efforts to accurately and promptly disseminate information on the current decommissioning status in an easy-to-understand manner. To that end, in addition to continuously providing opportunities for face-to-face initiatives, including site visits and round-table talks, TEPCO should continue to utilize 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.

Therefore, NDF is working to communicate the progress of the decommissioning to local residents in Fukushima Prefecture, including the 12 municipalities affected by the nuclear disaster, and dialogue sessions through two-way communication to sincerely address concerns and questions. These efforts will continue in 2025 (past sessions: held in June 2024 in 13 municipalities, November to December 2024 in 16 municipalities, and May to December 2025 in 16 municipalities, with two sessions planned in each area). Additionally, TEPCO is also implementing the inspection tours of Fukushima Daiichi NPS and Discussion Sessions as an opportunities for two-way communication through dialogues with the local community, and needs to continue these efforts in FY 2025.

(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.

Furthermore, with orders for local companies in decommissioning operations being mainly placed indirectly through prime contractors, the understanding and cooperation of each prime contractor is essential for the greater participation of local companies. Although prime contractors have been focusing on involving local companies to date to contribute to the reconstruction of Fukushima, TEPCO and relevant organizations such as NDF should develop an environment in which it would be even easier in the future for prime contractors to realize the participation of local companies, by taking stock of their such initiatives and of the issues raised and opinions from the viewpoint of prime contractors, sharing understanding and holding discussions. For this purpose, the first meeting of the Fukushima Decommissioning Council for Coexistence with the local community (hereinafter referred to as the “Council”) was held in January 2025. In order to expand the participation of local companies, the Council will share the initiatives of both the public and private sectors, exchange opinions, and discuss necessary measures for building a public-private partnership.

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. While properly understanding such intentions and needs of local companies, TEPCO and prime contractors should unitedly show their 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 through opportunities such as council meetings, as well.