Technical Strategic Plan 2022 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.

Overview

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Nuclear Damage Compensation and

Decommissioning Facilitation Corporation

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1. Introduction

The long-term approach to the decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc. (hereinafter referred to as the "Fukushima Daiichi NPS") has proceeded under “the Mid-and-Long-term Roadmap towards the Decommissioning of Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.” (hereinafter referred to as “Mid-and-Long-term Roadmap”), developed by the Japanese Government.

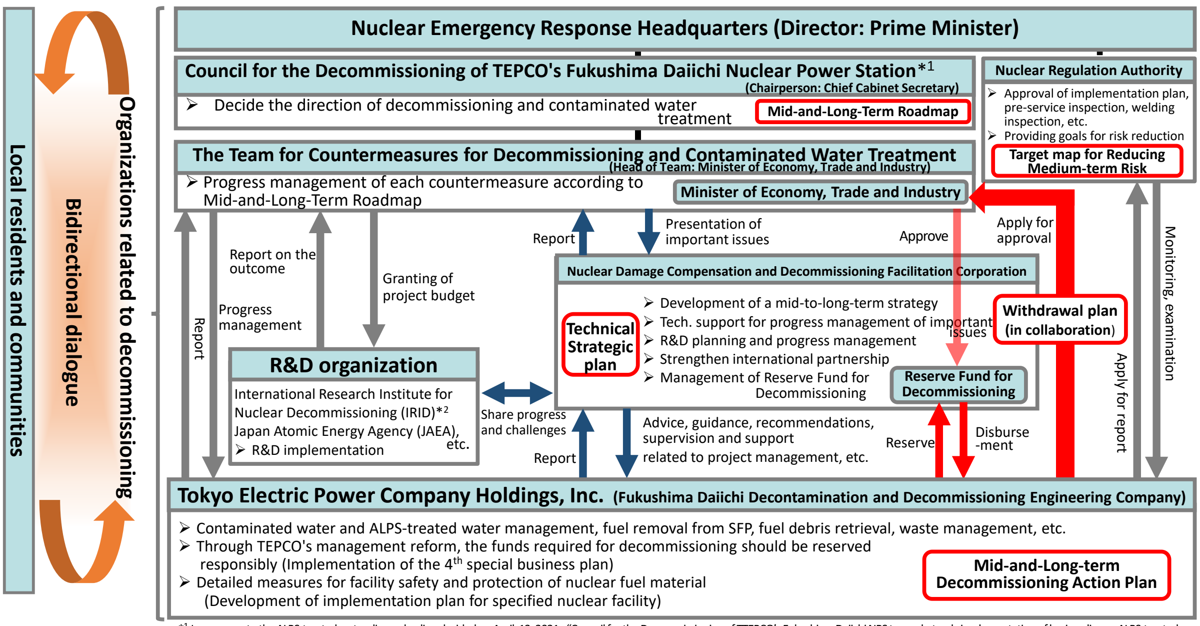
In March 2022, the earthquake occurred with its seismic center off the coast of Fukushima Prefecture, measured a lower 6 on the Japanese seismic intensity scale of 7. However, there was no leakage of radioactive materials into the environment and no significant impact on the plant operations. The Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc. (hereinafter referred to as “TEPCO”) is avoiding any effect on safety assurance caused by personnel shortages by taking thorough infection prevention measures against new coronavirus infections, which have been ongoing since FY2020. Nonetheless, the effects of global action restrictions and semiconductor shortages are unavoidable, and efforts are being made to minimize these effects. Under these circumstances, the decommissioning of the Fukushima Daiichi NPS is being prepared for the trial retrieval of fuel debris (internal investigation and fuel debris sampling) in Unit 2. Theis trial retrieval (internal investigation and fuel debris sampling) is the final stage of Phase 2 as indicated in the Mid-and-Long-term Roadmap and will be the basic form of on-site configuration for the future fuel debris retrieval work. Therefore, this phase requires more careful and cautious preparation. After transited to Phase 3-[1], preparations for full-scale debris retrieval and efforts to complete fuel removal from the spent fuel pools in all units will be promoted.

Nuclear Damage Compensation and Decommissioning Facilitation Corporation (hereinafter referred to as "NDF") has supported efforts related to the decommissioning of the Fukushima Daiichi NPS as an organization that conducts research and development, as well as provides advice and guidance, required for decommissioning since 2014. This "Technical Strategic Plan for Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station" (hereinafter referred to as the "Technical Strategic Plan"), as a part of these supports, has been compiled annually since 2015, with the objectives of providing a solid technical basis for the Mid-and-Long-term Roadmap and contributing to its smooth and steady implementation, consideration of revisions, and achievement of the goals of the Nuclear Regulation Authority (NRA)'s "Measures for Mid-term Risk Reduction at TEPCO’s Fukushima Daiichi NPS (hereinafter referred to as “Target Map for Reducing Medium-term Risks”)", as well as providing a basis for “The Policy for Preparation of Withdrawal Plan for Reserve Fund for Decommissioning” (hereinafter referred to as “the Policy for Preparation of Withdrawal Plan”).

1.1 Structures and systems toward the decommissioning of the Fukushima Daiichi Nuclear Power Station

The division of roles among the organizations directly involved in the decommissioning of the Fukushima Daiichi NPS, including the Japanese government, NDF and TEPCO, as well as organizations specializing in R&D, such as the International Research Institute for Nuclear Decommissioning [IRID] and the Japan Atomic Energy Agency [JAEA], is shown in Fig 1, which also indicates how the abovementioned systems are implemented.

Based on this division of roles, TEPCO has been working to build and strengthen the project management structure, and is in the process of making it more effective by enhancing and upgrading the management methods, in order to make systematic and steady progress in addressing each issue with a view to the mid-to-long-term decommissioning work. From the financial perspective, NDF has been carrying out the management of a reserve fund for decommissioning to ensure immediate decommissioning work. Under this management task, NDF is to (1) manage the fund for decommissioning appropriately, (2) manage the implementation structure for proper decommissioning, and (3) steadily manage the decommissioning work based on the Reserve Fund for Decommissioning, and NDF is assigned roles and responsibilities as an organization to manage and oversee TEPCO's decommissioning activities. NDF prepared "The Policy for Preparation of Withdrawal Plan ", which was drawn up based on the "Technical Strategic Plan", and presented to TEPCO the work goals and main activities to be incorporated in the Withdrawal Plan for reserve fund for decommissioning, and evaluated the appropriateness of TEPCO's efforts in the process of jointly preparing the Withdrawal Plan for reserve fund for decommissioning from the perspective of symbiosis and communication with the community, etc. (Fig. 2).



*1 In response to the ALPS-treated water disposal policy decided on April 13, 2021, "Council for the Decommissioning of TTEPCO's Fukushima Daiichi NPS toward steady implementation of basic policy on ALPS-treated water disposal" was founded.

*2 TEPCO, a decommissioning project operator, participates as a member of IRID and shares the needs, challenges, and results of research and development.

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

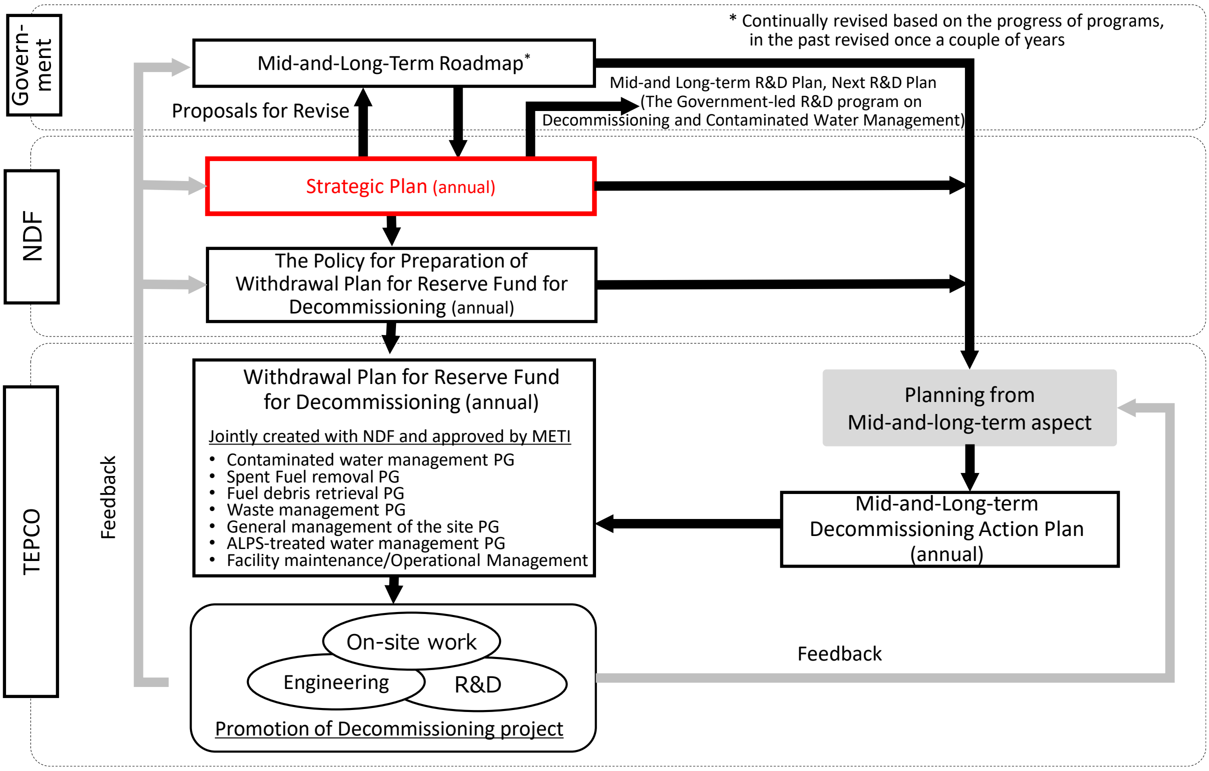


Fig. 2 Positioning of the Technical Strategic Plan based on the Reserve Fund

1.2 The Technical Strategic Plan 2022

The Technical Strategic Plan 2022 features the status of efforts toward trial retrieval from Unit 2 (internal investigation and fuel debris sampling), the status of the examination of methods toward further expansion of fuel debris retrieval in scale, the status of efforts toward the discharge of ALPS-treated water into the ocean, and analytical strategies for promoting decommissioning.

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

2.1 Basic policy for the decommissioning of the Fukushima Daiichi NPS

The basic policy for the decommissioning of 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" by taking measures specifically designed to reduce risks.

In proceeding with decommissioning, it is important for ensuring the safety of decommissioning operations to consider flexible risk reduction strategies that require a long-term and overall perspectives on the balance of risks based on the safety features.

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

In Phase 3-[1], several processes for risk reduction will be carried out in parallel according to the milestones in the Mid-and-Long-term Roadmap.

- Aim to complete fuel removal from the spent fuel pools of Units 1 - 6.
- Undertake trial retrieval of fuel debris and promote a gradual expansion of the scale of retrieval.
- Minimize and stably maintain the amount of contaminated water generated.
- Eliminate the temporary storage of rubble etc., as a waste management measure.

Regarding fuel debris retrieval, preparation of methods for further expansion of fuel debris retrieval in scale, which will be full-scale decommissioning work, will be promoted. Even though more than about eleven years have passed since the declaration of the cold shutdown state and the current state of temperature and pressure inside the primary containment vessel (hereinafter referred to as "PCV") is stable, conditions may change with the start of fuel debris retrieval. As the retrieval progresses, the risks attributable to fuel debris will decrease. However, it is undeniable that risks that were previously perceived as small may become relatively large or that unknown risks may become apparent. To effectively respond to risks toward further expansion of fuel debris retrieval in scale, it is necessary to improve the ability to observe conditions inside the PCVs where changes in these risks are likely to occur. Therefore, despite the high degree of difficulty, consideration should be given to expanding the type and number of monitoring targets, while taking into account the current purpose of the monitoring parameters and the number of monitoring devices in the PCVs and difficulties in on-site operation. For example, the dust concentration in the PCVs is expected to increase with fuel debris retrieval work in the case of further expansion of fuel debris retrieval in scale. If the dust concentration in the PCVs can be measured in a phase of preceding trial retrieval and gradual expansion of the retrieval scale, and the correlation between the location and scale of the retrieval operations and the dust concentration can be determined, it is possible to reduce the uncertainty associated with retrieval operations and improve work efficiency while maintaining an appropriate safety margin.

Once the condition inside the PCVs can be observed from a more multifaceted perspective, it is expected to provide a basis for whether or not the facilities being considered are required for further expansion of fuel debris retrieval in scale, contributing to the optimization of resources.

In addition to promoting the design, manufacture, and installation of systems related to the retrieval methods, it is also important to secure and train operators and maintenance personnel, develop a management framework, and establish a rational analysis framework for retrieved fuel debris.

2.1.1.1 Risk reduction

2.1.1.1.1 Further measures to reduce the migration of radioactive materials from PCVs

- Gaseous and dusty radioactive materials

Toward fuel debris retrieval, containment ability should be further enhanced by reducing the migration of gaseous and dusty radioactive materials that are prone to migration from PCVs. Specifically, the effectiveness of the reduction in the amount of dust transferred outside the PCV should be observed by PCV pressure equalization (slightly negative pressure) and an enhanced dust concentration monitoring function in the PCVs, as shown in 2.1.1.

- Liquid radioactive materials

The migration of liquid radioactive materials, which are almost as easily migrated as gaseous and dusty radioactive materials, should be controlled without fail. Specifically, drainage of the water retained in the suppression chamber (hereinafter referred to as “S/C”) and other systems that TEPCO is currently undertaking should be accelerated to minimize the amount of PCV water.

In proceeding with the above, the tests available with the current system configuration, such as reactor water injection shutdown tests and nitrogen supply reduction tests, should be actively performed in accordance with the “concept of preliminary implementation and utilization of the obtained information in the latter stages” described in 2.3.2, to assess the feasibility, and determine areas and difficulty of the issue.

2.1.1.1.2 Preparation for long-term risks to the integrity of reactor pressure vessels (RPVs), primary containment vessels (PCVs), and reactor buildings containing fuel debris

The reactor pressure vessels (hereinafter referred to as "RPVs") and the PCVs were directly affected by the accident. It has been found that the molten fuel damaged the bottom of the RPVs and the PCVs were partially damaged by overheating and overpressure.

At the PCV bottom, it is assumed that effects due to contact with the molten core materials and their heat occurred. For this reason, prudent approaches should be taken to maintain the long-term integrity, including the containment performance of RPVs and PCVs and the strength of reactor buildings, against threats of corrosion of metal materials, deterioration of containment performance, and degradation in strength of the affected concrete structural materials.

To achieve that, it is necessary to verify the damage condition inside the PCVs in a focused manner and proceed with an integrity assessment based on the latest information on the PCV interior, assuming long-term risks that may occur in the future, such as earthquakes and aging degradation. Given the limited information on damage conditions, this evaluation always involves uncertainty. Still, it is necessary to make diligent efforts to update the evaluation data and incorporate the latest in-core information for reducing uncertainty. Details of initiatives are shown in 3.1.2.6.1.5.

2.1.1.2 Requirement for the further expansion of fuel debris retrieval in scale

The following is required to conduct safe and reliable fuel debris retrieval toward the phase of further expansion of fuel debris retrieval in scale:

- Ensure that trial retrieval will be carried out while obtaining knowledge so that it can be utilized in subsequent gradual expansion of fuel debris retrieval and further expansion of fuel debris retrieval in scale.
- Proceed with designing, manufacturing, and installing systems related to retrieval methods.
- It is necessary to establish a system for securing, training and managing operators and complete necessary training.
- Since preliminary work for retrieval requires operations in the high-dose reactor building, due to the prolonged work it is important to improve the on-site environment and ensure exposure control and the long-term availability of workers.
- In preparation for hardware, it is necessary to complete environmental improvements in the surrounding area, such as dismantling and removing exhaust stacks and radioactive waste disposal buildings.
- Moreover, the organizations concerned need to discuss and develop an analysis plan, facilities for analysis, and an analysis framework for analyzing the retrieved fuel debris rationally.
- It is important to facilitate waste storage that does not hinder the above operations.

Specific initiatives for the above are discussed in Chapters 3 and 4.

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 (hereinafter referred to as "SED") developed by the Nuclear Decommissioning Authority (hereinafter referred to as "NDA") to express the magnitude of risk (risk level) for radioactive materials. In this method, risk level can be expressed by the product of "Hazard Potential", which is an index of the impact of internal exposure in the event of human intake of radioactive material, and "Safety Management", which is an index of the likelihood that an event will occur.

The major risk sources of the Fukushima Daiichi NPS are summarized in Table 1. The current risk levels assigned to these respective risk sources are expressed in Fig. 3 with "Hazard Potential" and "Safety Management" as the axes.

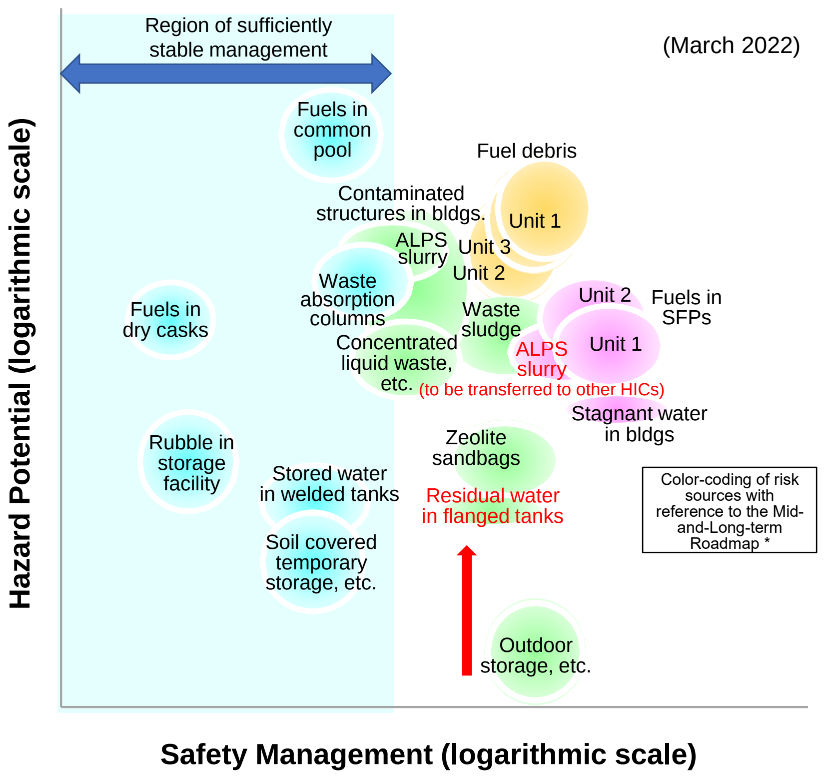
As events that were not anticipated have occurred during the long period of the decommissioning work, it is important to identify unexpected risks. Although it is not easy to identify such risks, when an unexpected event occurs, analyzing the event to clarify causes that had not been anticipated before provides a clue for risk identification.

At the event of total-β contamination leakage in the rubble temporary storage area reported on March 25, 2021, leakage of radioactive materials occurred from a container whose contents were not identified. It has so far been assumed that solid content such as rubble would not immediately transfer radioactive materials to the environment due to container damage. However, subsequent analysis suggested that corrosion of the inner surface of the container caused leakage. In light of this event, however, it is important for risk identification to understand physicochemical state and its changes over time, in addition to the location of the risk sources and radioactivity. At the time of the earthquake on February 13, 2021, with its epicenter off the coast of Fukushima Prefecture, lowering of the PCV water levels at Units 1 and 3, and sliding of tanks on site exceeding the sliding amount evaluated at the time of tank installation were observed. At the time of the earthquake on March 16, 2022, with its epicenter off the coast of Fukushima Prefecture, a lowering of the PCV water levels at Units 1 and 3 was observed and the over-turning of containers in the temporary storage area was confirmed. For the PCVs for which the current state is not well-understood, understanding the damage condition by internal investigation and assessment of the situation at the accident, and estimation of aging by monitoring/evaluation are useful for risk identification. Regarding external events such as natural disasters, it is necessary to thoroughly evaluate in advance the consequences of and the necessity of countermeasures against beyond-design-basis events in existing/new systems.

Although none of the above events resulted in significant consequences, it is important to carefully analyze the events using methods such as root cause analyses, and to identify risks that had not been anticipated to in order help prevent the occurrence of significant consequences. For this purpose, TEPCO needs to make efforts to learn from the unexpected events as described above.

Table 1 Major risk sources at the Fukushima Daiichi NPS

Fuel debris		Fuel debris in RPVs/PCVs in Units 1 to 3
Spent fuel	Fuel in SFPs	Fuel assemblies stored in the spent fuel pools (SFPs) in Units 1 and 2
	Fuel in the Common Spent Fuel Storage Pool	Fuel assemblies stored in the Common Spent Fuel Storage Pool
	Fuel in dry casks	Fuel assemblies stored in dry casks
Contaminated water, etc.	Stagnant water in buildings	Contaminated water accumulated in the reactor buildings of Units 1 to 3, process main building and high-temperature incinerator building, and sludge containing α-nuclides at the bottom of buildings of Units 1 to 3
	Zeolite sandbags	Zeolite, etc. in sandbags placed on the basement floors of the process main building and high-temperature incinerator building
	Stored water in welded tanks	Strontium-treated water and ALPS-treated water, etc. (ALPS-treated water and water under treatment) stored in welded tanks
	Residual water in flanged tanks	Concentrated saltwater and sludge containing α-nuclides left at the bottom of flanged tanks
Secondary waste generated by water treatment	Waste sorption vessels, etc.	Spent sorption vessels, etc. generated from various contaminated water treatment systems such as a cesium sorption apparatus
	ALPS slurry	Slurry and waste absorbents generated during treatment by the multi-nuclide removal equipment and added multi-nuclide removal equipment, and stored in high integrity containers (HIC)
	ALPS slurry (to be transferred to other HICs)	ALPS slurry stored in HICs whose accumulated absorbed doses exceeded the criterion value of 5,000kGy (accumulated absorbed dose with confirmed HIC's structural integrity against drop) or evaluated to be close to the criterion value among the HICs affected by beta irradiation, which are planned to be transferred to other HICs by the end of FY2023.
	Sludge generated at the decontamination device	Flocculated sludge generated during the operation of the decontamination system
	Concentrated waste liquid, etc.	Concentrated waste liquid generated by evaporative concentration of concentrated salt water with further volume reduction by concentration, and carbonate slurry collected from the concentrated waste liquid
Rubble, etc.	Solid waste storage facility	Rubble (30 mSv/h and above) stored in the solid waste storage facility
	Soil-covered temporary storage, etc.	Rubble stored in the soil-covered temporary storage facility and containers (1-30 mSv/h), felled trees stored in the temporary storage pool
	Outdoor storage, etc.	Rubble stored in outdoor sheet-covered storage (0.1-1 mSv/h), rubble stored in outdoor storage (below 0.1 mSv/h), felled trees stored in outdoor storage
Contaminated structures, etc., in the buildings		Structures, pipes, components, and other items (shield plugs, standby gas treatment system pipes, etc.) inside the reactor buildings and PCVs/RPVs that are contaminated with radioactive materials dispersed due to the accident; and activated materials generated from operation before the accident



* Risk sources that are "relatively high risks given high priority" are shown in pink, those that are "immediate risk unlikely, but risk may grow when handling with haste" are shown in yellow, those that are "increased risk unlikely in the future, but appropriate decommissioning efforts are required" are shown in green, and those that are in the "sufficiently stable management" region are shown in light blue.

The red letters present risk sources that have changed significantly from the evaluation of the Technical Strategic Plan 2021 (as of March 2021).

The origin of the arrow indicates the location for the residual water in flanged tanks reported in the Technical Strategic Plan 2021, which has been moved upward to reflect the results of the analysis of the radioactivity concentration prior to the treatment. ALPS slurry (to be transferred to other HICs) was separated from ALPS slurry this time and shown in pink, as is the fuel in the pool.

Fig. 3 Risk levels posed by the major risk sources at the Fukushima Daiichi NPS

2.2.2 Risk reduction strategy

2.2.2.1 Interim targets of the risk reduction strategy and progress

Measures for risk reduction include the reduction of the "Hazard Potential" and the reduction of the "Safety Management" level. Of the various risk reduction measures, reduction of the "Safety Management" level is generally considered to be easily realized. Consequently, the decommissioning of the Fukushima Daiichi NPS, which is implemented under the basic policy of "to continuously and quickly reduce the risks arising from the radioactive materials caused by the accident and that do not exist in normal nuclear power plants" (refer to Section 2.1), should first focus on steadily managing risk sources by keeping them in higher-integrity facilities to lower their Safety Management levels. The interim target of the risk reduction strategy is to bring the risk levels into the "Sufficiently stable management" region (the pale blue area) as shown in Fig. 3.

Regarding the progress of work from Technical Strategic Plan 2021 toward this goal, Fig. 3 shows the status of treatment of the residual water (concentrated salt water) at the bottom of the flanged tanks, and the need to replace some high integrity containers (hereinafter referred to as “HIC”s) storing ALPS slurry in consideration of the effect of β-ray irradiation.

Of the residual water in flanged tanks, sludge sedimentation containing α-nuclides has been confirmed in the tanks that received the residual bottom water when dismantling tanks in each tank area, recovery of the remaining water is currently underway. Supernatant water has been transferred to the process main building, and the water level is lower than assessed in the Technical Strategic Plan 2021. Only one tank contains residual water, including the sludge, and the collection of the sludge through a filter is being carried out. In evaluation incorporating total α-nuclides concentrations and the high strontium concentrations identified by the analysis of radioactive concentrations prior to the treatment (analysis of the residual water sampled from two tanks on July 21 and August 5, 2021), high strontium concentrations have a significant impact, thereby increasing the hazard potential compared to the Technical Strategic Plan 2021. However, it is a reflection of the findings from the analysis and does not indicate the risk itself has increased. Not only in this case, but in other cases, there is uncertainty in risk source information. If an assessment is conducted based on estimates with limited information or fragmentary sampled data, there is a possibility of the risk being underestimated or overestimated.

Regarding the ALPS slurry, among the HICs affected by β irradiation, those accumulated absorbed doses have exceeded the criterion value of 5,000kGy (accumulated absorbed dose with confirmed HICs structural integrity against drop[1]) or are evaluated to be close to exceeding the criterion value, and those ALPS slurry are planned to be transferred to other HICs by the end of FY2023 is shown in pink in Fig. 3. Since the number of HICs whose accumulated absorbed dose is close the criterion value will gradually increase with time, it is important to carry out transfer operation steadily and manage not exceeding the criterion value. To this end, the slurry stored in HICs that exceeds the criterion value should be eliminated by systematically transferring them by the end of FY2023. After that, the transfer operation should be made before the criterion value is exceeded in a systematic manner. In addition, an early transition to storage in containers with long-term integrity leads to an intrinsic reduction in the risk of deterioration over time. TEPCO is reviewing the design of containers with long-term integrity in the design for stabilizing slurry, and this should be promoted without delay. As the decommissioning work becomes more prolonged, important actions are monitoring and managing risk sources in consideration of the deterioration of facilities and systems and promptly bringing risk sources to a stable and controlled state.

In considering the station-wide risk reduction strategy for the Fukushima Daiichi NPS, the above-mentioned SED is a quantitative indicator of risks attributable to radioactive materials at a certain time, and is an effective method for prioritizing risk sources for risk reduction.

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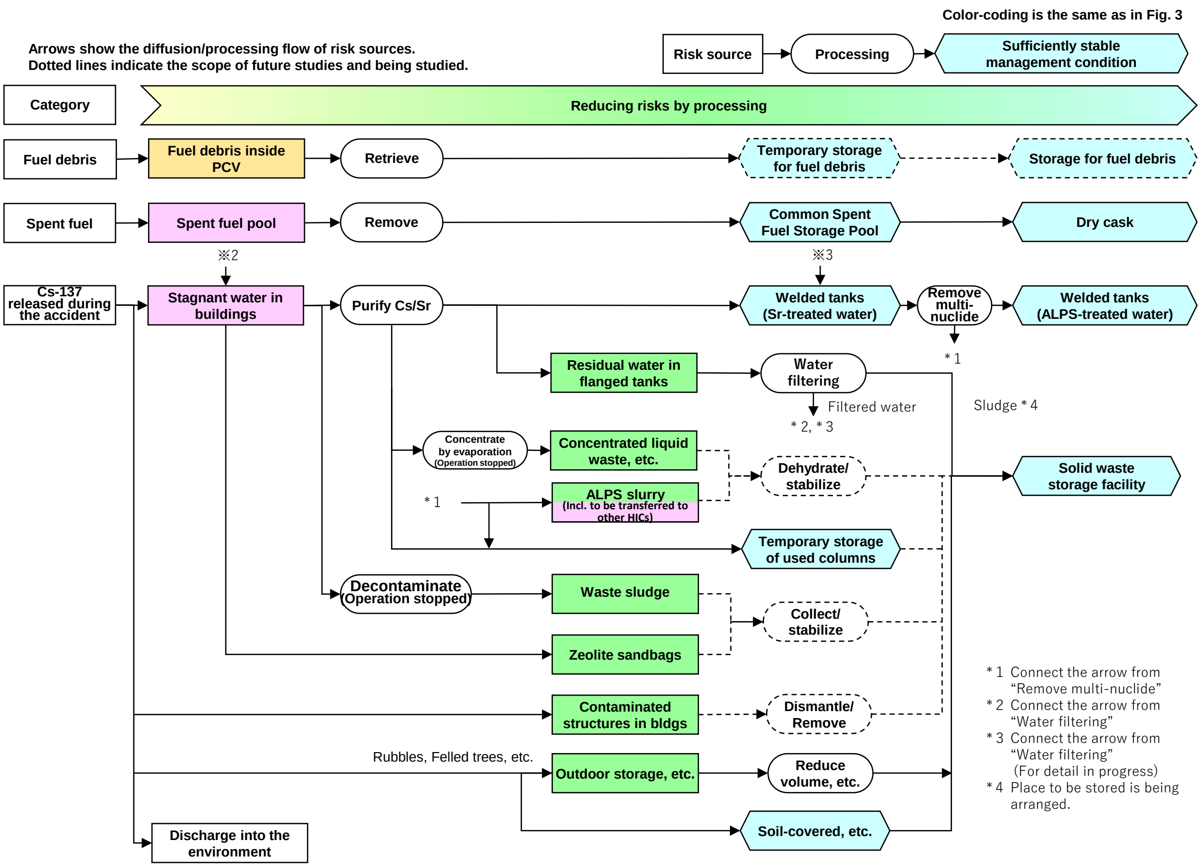
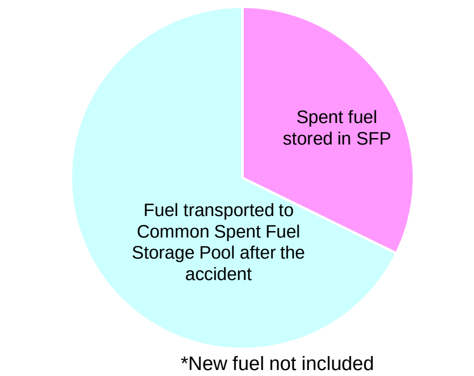
[1] The allowable strain was established from the material test results of HIC polyethylene specimens irradiated with 5,000kGy of beta radiation, and the maximum strain obtained from the drop analysis was less than the allowable strain.

2.2.2.2 Risk reduction process for major risk sources and its progress

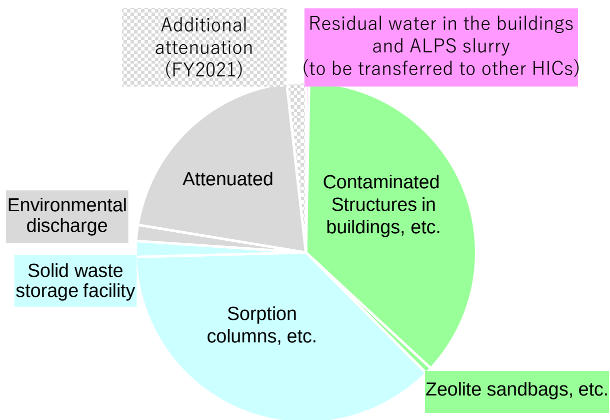
Fig. 4 shows the process to bring major risk sources into the “Sufficiently stable management” region as the interim goal, and an example of representing the decommissioning work progress along this process. Fig. 4 (a) shows the outline flow of the decommissioning work to date and the future plans to represent the overall decommissioning process in a comprehensive way. Using the coloring in Fig. 3 to indicate the risk level of each risk source, Fig. 4(a) also shows the flow of risk reduction. Based on this flow, it is possible to visualize how the risk sources have changed compared with the time of the accident by applying it to fuel debris, spent fuel, and Cs-137 released during the accident. As changes from Technical Strategic Plan 2021, the treatment process of the residual water in the flanged tanks (sludge recovery by water filtering) are shown, and the ALPS slurry is indicated in green and pink, some ALPS slurry is planned to be transferred in light of the impact of β irradiation. The number of spent fuel assemblies as an indicator to make the work progress easier to see in Fig. 4 (b), and for Cs-137, the estimated radioactivity (Bq) common to various risk sources as an indicator in Fig. 4 (c) both indicate the progress of the decommissioning work by representing the status of transition to the “Sufficiently stable management” region in a pie chart format. Fig. 4 (b) has made no progress since Technical Strategic Plan 2021. Fig. 4 (c) incorporates the increase/decrease in Cs-137 due to the decrease in the stagnant water in buildings, the increase in waste sorption vessels, the increase in the storage volume in solid waste storage, and the increase of attenuation in FY 2021. In this Figure, the significant increase in the percentage of attenuation is shown in light gray. In light of the impact of β irradiation, the ALPS slurry stored in HICs to be transferred is transferred to the pink area.



(a) Risk reduction process



(b) Number of fuel assemblies of spent fuel (Units 1 to 4)



(c) Radioactivity of Cs-137 released at the accident (Units 1 to 3)

Fig. 4 Risk reduction process for major risk sources and its progress (example as of March 2022) (Attenuation in Fig. 4 (c) takes into account radioactive decay of Cs-137 from the time of the accident to the end of March 2022)

2.2.2.3 Basic approach to risk reduction

The decommissioning of the Fukushima Daiichi NPS is a project that involves considerable uncertainties. To date, the internal status of the PCVs of Units 1 to 3 has been estimated to some extent through simulation of the accident development process, estimation of the places with fuel debris by muon-based fuel debris detection technology, placement of investigation equipment into the PCVs, radiation dose measurement and video photographing in the buildings, and other means. However, there are still significant uncertainties. Eliminating these uncertainties requires many resources and, in particular, a considerable amount of time. In order to realize prompt reduction of risk, it is necessary to promote the decommissioning work through a flexible and prompt approach, based on the directions determined with previously obtained experience and knowledge, and with experiment and analysis-based simulation, making safety the top priority, even though uncertainties remain to a certain extent.

Regarding the perspective from which these comprehensive decisions will be made, NDF summarizes the following five guiding principles:

(Five guiding principles)

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

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

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

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

2.3 Approach to ensuring safety during decommissioning

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

Decommissioning of the Fukushima Daiichi NPS containing the reactors involved in the accident is an unprecedented activity that takes place in a peculiar environment different from that of a normal reactor, and therefore, to ensure safety, the following characteristics (peculiarities) regarding safety should be fully recognized:

- A large amount of radioactive material (including α-nuclides that have a significant impact in 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.
- Difficulty in accessing the site and installing 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

Consequently, TEPCO, as the operator of the decommissioning project, needs to pay special attention to the following points in proceeding with the decommissioning based on the five guiding principles.

Firstly, with regard to "safety": There is great uncertainty about the state of radioactive materials and containment barriers, and on-site access and installation of instrumentation devices to reduce the uncertainty are also restricted. Under these circumstances, a large amount of atypical and unsealed radioactive material will be handled in an incomplete state of containment. Therefore, the starting point for all reviews should be confirmation of the feasibility of ensuring safety with a wide range of possibilities (cases) assumed. At the same time, with regard to "safety", it is important not to prolong the work period in light of risk reduction over the entire work period. Therefore, it is necessary to avoid excessive safety measures and to take optimum safety measures (ALARP). Such perspective on "safety" (the safety perspective) should be reflected in the decommissioning work review.

Secondly, with regard to "field-oriented":

- The on-site environment is in a peculiar state that includes a high level of radiation, and therefore attention should be paid to the feasibility of construction/implementation of safety measures on site.
- An approach through design alone has limitations due to significant uncertainties.

From the above-mentioned reasons, it is essential to accurately apply the information gained on site into engineering. In order to ensure the implementation of unprecedented engineering such as fuel debris retrieval, the views and feelings of the individuals and organizations (operators) that are responsible for the on-site work (including operation, maintenance, radiation control, instrumentation, analysis, etc.) and very familiar with actual site should be highly respected. Moreover, it is important to respect their perspectives and judgements directly based on the site (the operator's perspective). In promoting the prolonged decommissioning work, it is necessary to maintain and strengthen the operator's perspectives/feelings, and TEPCO themselves should inherit their perspectives. Therefore, TEPCO needs to take action that always accounts for the worksite in the overall decommissioning work process, such as by inviting outside experts and technicians with operator's perspectives for coaching/educational training, including experienced workers in difficult operations and those who experienced on-site operations.

This section describes the importance of the safety assurance measures in terms of the characteristics of Fukushima Daiichi NPS based on safety assessment which includes the operator's perspective. Then, it describes the operator's perspective-specific importance that should be incorporated at multiple levels in the safety assurance process.

2.3.1.1 Optimization of judgement with a safety assessment as its basis and ensuring timeliness in decommissioning

With an aim of reducing risk through decommissioning, it is most important to take appropriate measures and ensure the safety of work in which a large amount of radioactive material is handled that is technically difficult and has significant uncertainties, such as fuel debris retrieval. Thus, decommissioning work should be carried out with such "safety perspective".

Specifically, when designing safety measures for each decommissioning activity, it is essential to make decisions based on the five guiding principles after conducting a thorough safety evaluation and confirming that the required safety is ensured. As mentioned above, the decommissioning work of the Fukushima Daiichi NPS is unprecedented and has significant uncertainties. Using deliberated safety evaluation as the basis for making decisions regarding safety measures, the decisions will not be significantly unstable (that is, without devoting too little or excessive resources), and thus necessary, sufficient, and reasonably feasible safety measures can be realized (optimization of judgment based on safety assessment). In regard to reasonably feasible safety measures, it is particularly important in the safety assessment of the Fukushima Daiichi NPS to conduct safety assessment with incorporating operator's perspective stated in 2.3.1.2.

In addition, the importance of making progress in the decommissioning work without delay (the importance of time-axis-conscious action) can be mentioned as "the safety perspective" unique to the decommissioning of Fukushima Daiichi NPS. Considering the high radiological impact that has already materialized, and the possibility of further degradation of containment barriers, etc., making progress in the decommissioning work without delay will have great significance for ensuring the safety of the entire decommissioning process from a medium-and-long term perspective. Therefore, it should be noted, for ensuring safety, that different perspectives from normal reactors are required, which have a certain margin in terms of human, physical, and financial resources and have low radiological impacts and high stability. On the condition that safety is secured, rational judgement should be made on resource allocation and the time-axis-conscious progress in the decommissioning work without delay based on the relationship with the overall balance (ensuring timeliness in decommissioning activities).

2.3.1.2 Ensuring safety by incorporating "the operator's perspective"

To ensure that safety measures are truly effective, it is necessary to satisfy the needs from the standpoint of those who actually perform the operations and tasks on site, "the operator's perspective" (perspectives and judgements from the standpoint of those who are familiar with the site and perform operations and tasks on site) is important. In addition to this standpoint, when determining the feasibility of safety measures in decommissioning the Fukushima Daiichi NPS, it is necessary to take into account the fact that the facility has suffered from the accident, and its decommissioning requires an unprecedented approach in a peculiar environment, such as one with high radiation levels, unlike normal reactors.

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

The on-site conditions at the Fukushima Daiichi NPS containing the reactors involved in the accident includes considerable uncertainties. If the whole operation of a large-scale project such as fuel debris retrieval is to be designed only with existing knowledge, assumptions of an extremely large safety margin and wide range of technical options will be needed. Thus, extension of the work period or the risk of rework will be unavoidable. As a result, the feasibility or predictability of the entire project may be reduced, leading to a delay in the entire decommissioning, a rise in the decommissioning cost, or increased radiation exposure of workers.

However, considering the environment with an already high radiation level, further deterioration of containment barriers, and the possibility of future major natural events (such as earthquakes or tsunamis), it is necessary to immediately improve the state of such risks and reduce uncertainties. Therefore, a "sequential type approach" is important where the whole operation is divided into several stages, "operation at first stage" is implemented for which practical safety can be ensured, and then the information obtained there is utilized in the next stage. With this approach, operation proceeds with safety ensured through monitoring the condition inside reactor, restricting operational actions and flexible on-site responses at each stage of the process. The information obtained at each stage of operation and testing is utilized in the design of subsequent stages. This approach reduces uncertainties in the operations in subsequent stage as well as improve the reliability of safety assurance and rationalize design.

TEPCO should actively introduce an approach like this into actual engineering and project management.

Hereafter, it is recommended to make sequential type approach clear as a policy, in which the information to be gained through on-site operation should be fully incorporated and accumulated as knowledge for ensuring safety. For example, in the reactor water injection shutdown tests that TEPCO has been conducting since FY 2019, the risk associated with water injection shutdown has been identified, and knowledge has been accumulated. In the future, efforts should not be limited to identifying risks and accumulating knowledge during the shutdown of water injection but should be expanded to account for acquiring a basis that contributes to the design of water injection systems for fuel debris retrieval.

It is important to accumulate successful/unsuccessful experience gained in the process of these sequential approach as a track record, allowing gradual reduction in major uncertainties in the overall decommissioning work in the future. This will lead to steady progress in decommissioning and contribute to ensuring safety in decommissioning the Fukushima Daiichi NPS from the perspective of risk reduction in the medium-and-long term.

The approach to risk reduction and ensuring safety in the decommissioning of the Fukushima Daiichi NPS, as described in this chapter, needs to be promoted with the broad understanding of not only the people directly involved but also the local people. Consequently, it is necessary to cooperate with each other to reduce risks based on the approach to ensuring safety based on their respective positions. In doing so, it is important to establish a system for on-going risk monitoring which enables a wide range of people to easily understand how the overall risks at the site have been continuously reduced through the decommissioning work, and to communicate such progress to the public. In addition to sharing the status of risks through the Technical Strategic Plan on a constant basis, NDF is considering providing the status of risk reduction along with the progress of the decommissioning work described. 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 a proactive manner.

3. Technological strategies toward decommissioning of the Fukushima Daiichi NPS

3.1 Fuel debris retrieval

3.1.1 Targets and progress

(Targets)

(1) Retrieve fuel debris safely after thorough and careful preparations, and bring it to a state of stable storage that is fully managed.

(2) Trial retrieval in Unit 2 was scheduled to begin within 2021, but the process will be reviewed to improve work safety and reliability during retrieval in light of the impact of the COVID-19 pandemic, ongoing mock-up tests at the Naraha Center for Remote Control Technology Development since February 2022, and the status of the on-site preparatory work in Unit 2, and trial retrieval is expected to begin in late FY 2023. Continue a series of work, including gradual expansion of fuel debris retrieval, to acquire the knowledge and experience necessary for further expansion of fuel debris retrieval in scale.

(3) With regard to further expansion of fuel debris retrieval in scale, consideration will be given to the methods including those for containing, transferring, and storing of fuel debris, by assessing fuel debris retrieval in Unit 2, internal investigations, research and development, and the on-site environmental improvement, etc.

(Progress)

① Unit 1

PCV internal investigations have been conducted using a boat-type access investigation device with a diving function (hereinafter referred to as “underwater ROV”), which can be equipped with various measurement sensors. The underwater ROV is inserted into the PCV through the penetration X-2 to access the basement floor outside the pedestal. So far, visual investigations and deposit thickness measurements have been in progress. In the visual investigations, lump deposits have been observed outside and inside the periphery of the worker access opening in the pedestal. However, whether they are existing structures or fuel debris has not been determined. In addition, reinforcing bars were observed in the vicinity of the worker access opening, and it was confirmed that concrete in the pedestal area was partially missing. Regarding this matter, IRID conducted a seismic assessment of the partially damaged pedestal in FY 2016 under the Project of Decommissioning and Contaminated Water Management and confirmed that its supporting function was not significantly impaired.

Further investigations are planned to observe the distribution of deposits widely scattered at the bottom of the outside of the pedestal, the presence or absence of fuel debris in deposits, sampling/analysis of deposits, and the condition of structures inside the pedestal.

② Unit 2

The 2019 Mid-and-Long-term Roadmap specified Unit 2 as the first implementing unit where fuel debris retrieval would be implemented, and trial retrieval was supposed to launch within 2021. The process has been delayed due to the impact of the COVID-19 pandemic, work proceeded to limit the delay to about one year.

Then, after completing the manufacture and verification tests of the arm-type access equipment (hereinafter referred to as “robot arm”) in the UK in June 2021, the equipment was brought to Japan and has been undergoing performance confirmation tests, mock-up tests, and training at the domestic factory (Kobe) since July 2021, and at the Naraha Center for Remote Control Technology Development, JAEA since February 2022. Modification and verification of the control software and improvements to some equipment, which are new requirements based on these tests, are being progressed. Furthermore, the plan is to expand one-through testing for higher reliability.

In addition, as on-site preparatory work, installation of the isolation chamber for opening hatch of the penetration X-6 started in November 2021. As countermeasures for the damage to the box rubber and the bent guide rollers (in response to the earthquake) in the isolation chamber that occurred during installation, replacement of the rubber box with metal plates, cutting off hatch handle of the penetration X-6, and structural changes to the guide roller are planned. In the future, work feasibility will be verified through factory mock-up testing. Remanufacturing of the isolation chamber is also under consideration in case any issues are identified in the verification results and installation condition of the isolation chamber after implementing countermeasures. As operations such as opening of the penetration X-6 hatch and removal of deposits in the penetration X-6 are planned, work should be carried out safely and carefully.

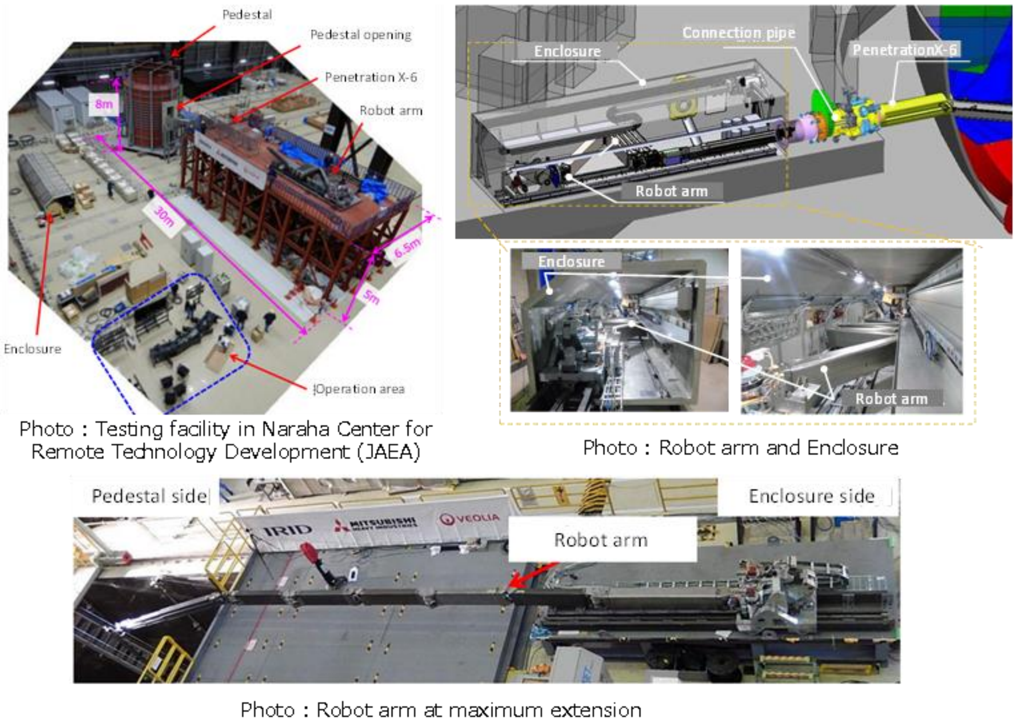
As described above, given the response status based on the mock-up test of the robot arm and the arrangement of countermeasures in on-site preparatory work, it has been decided to add another 1 to 1.5-years to the preparation period along with the preceding delay of about one year due to the impact of the COVID-19 infection to improve work safety and reliability and to change the process to start trial retrieval in late FY 2023.

A plan for the gradual expansion of fuel debris retrieval is also underway, and the retrieval device will be improved by increasing the weight capacity and enhancing accessibility while complying with specifications for the devices for trial retrieval (internal investigations and fuel debris sampling). In this plan, the requirements related to performance of the robot-arm and enclosures and the requirements at the design and installation have been clarified and examined. The retrieved fuel debris will be stored in container for fuel debris retrieval and transport container in the enclosure, and then transferred to the receiving/delivery cells on site and stored in temporary storage cells. In addition, some of the fuel debris will be collected in the receiving/delivery cells for analysis and transported to the facility for analysis. Designing of the retrieval device, receiving/delivery cells, and temporary storage cells is in progress (Fig. 5, Fig. 6).

③ Unit 3

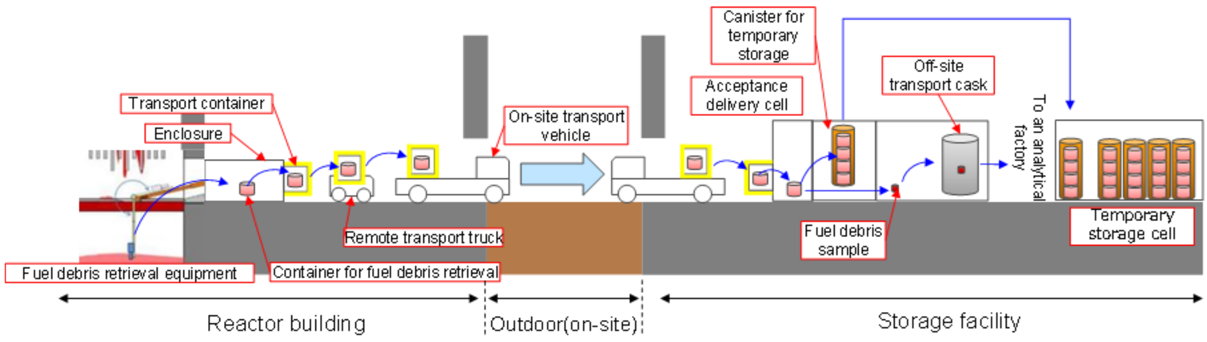
Regarding Unit 3, due to the high water level in the PCV, the plan is to lower the PCV water level in two steps, taking into account the conducting of the PCV internal investigation and the improved seismic resistance of the S/C. The plan for lowering the water level in Step 1 was to drain the PCV water by self-suction pumps using the existing pipe connected to the S/C to reduce the current water level below the first floor surface of the reactor building. However, after the earthquake on March 16, 2022, it was confirmed that the PCV water level was gradually declining. After the start of the planned reactor water injection shutdown tests in June, water injection was resumed to continue water level measurement because it was determined that the PCV water level had fallen below the lower end of the new PCV thermometer/water level gauge. After that, the amount of water injection was adjusted in July, confirming that the PCV water level was generally stable. Based on the above circumstances, for the plan to lower the water level in Step 1, monitoring of plant parameters will be continued, and a reduction of the amount of water injection or the shutting down of water injection will be discussed to install instruments at lower locations than current levels and lower the PCV water level. In Step 2 in the future, the plan is to connect the guide pipe to the S/C and lower the water level to the bottom of the S/C by underwater pumps installed inside the S/C.

Although retrieval methods for further expansion of fuel debris retrieval in scale were examined in the conceptual study, many challenging issues and risks associated with each discussed method were identified. Since FY 2022, studies have been conducted on countermeasures for these issues and risks from the perspective of feasibility.



(Prepared by NDF based on TEPCO and IRID materials)

Fig. 5 Image of fuel debris retrieval system
(Trial retrieval and subsequent gradual expansion of fuel debris retrieval)



(TEPCO material edited by NDF)

Fig. 6 Image from retrieval to temporary storage of fuel debris

3.1.2 Key issues and technical strategies to realize them

Since the understanding the situation inside the PCVs is still limited, the current design and the plan for on-site operations related to fuel debris retrieval should be continuously reviewed based on knowledge that will be obtained in the future, and it is also important to accurately incorporate the results of studies, research and development toward fuel debris retrieval.

The trial retrieval (internal investigation and fuel debris sampling) in Unit 2 will be the first retrieval of fuel debris, and it is necessary to make steady preparations to utilize the valuable information and experience obtained through these works in subsequent retrieval operations. Thereafter, the gradual expansion of fuel debris retrieval will be implemented based on the findings obtained from the retrieval in Unit 2. In addition, a conceptual study on further expansion of fuel debris retrieval in scale for Unit 3 is planned.

Since each unit is in a different situation, this section first describes each unit's fuel debris retrieval strategy in 3.1.2.1, followed by the strategies for trial retrieval (internal investigation and fuel debris sampling) in 3.1.2.2, and gradual expansion of fuel debris retrieval in 3.1.2.3, and further expansion of fuel debris retrieval in scale in 3.1.2.4. This chapter then describes the continuous accident analysis activities in 3.1.2.5, technical issues for technical requirements, and future plans in 3.1.2.6.

3.1.2.1 Fuel debris retrieval strategies in each Unit

(1) Unit 1

- Toward further expansion of fuel debris retrieval in scale, the retrieval methods should be examined by promoting R&D and engineering to apply the results on-site and based on the knowledge gained through trial retrieval in Unit 2 and the initial study results of the method for Unit 3.

- In the ongoing PCV internal investigation, the condition of the existing structures and distribution status of deposits outside the pedestal are being confirmed, an investigation inside the pedestal through the worker access opening is also scheduled. However, although the previous investigations and analyses using muon have evaluated that there is almost no fuel debris in the core, they were not direct investigations. Thus, a direct video investigation is required in a future study. As technological development for this purpose is in progress, the information obtained from these investigations should be incorporated as necessary when examining retrieval methods hereafter.

- The size of the RPV and PCV is smaller than Units 2 and 3 due to a lower plant output, and the layout of plant systems also differs. In addition, although it is expected to be clarified in a future investigation, the distribution of deposits inside the RPV and inside/outside the pedestal is considered to be different from Units 2 and 3. Therefore, it is necessary to examine retrieval methods considering these differences.

(2) Unit 2

- Preparations for trial retrieval are underway, and the plan is to gradually expand fuel debris retrieval. However, since there is no plan to retrieve all the fuel debris using the side-access method, it is necessary to examine methods for the further expansion of fuel debris retrieval in scale.

- Toward the gradual expansion of fuel debris retrieval, it is necessary to advance R&D and engineering for applying the results on-site, and then to promote design, manufacturing, and installation of fuel debris retrieval systems, safety systems (e.g., containment, fuel debris cooling, criticality control), temporary fuel debris storage, and maintenance systems for retrieval systems, based on the knowledge gained through trial retrieval.

- Toward further expansion of fuel debris retrieval in scale, it is necessary to examine the retrieval methods based on the knowledge gained through retrieval in Unit 2 and the initial study results of the method for Units 3.

- The previous PCV internal investigations (inside the pedestal) and investigations/analyses using muon indicated that a large amount of fuel debris is at the RPV bottom and there is a possibility of some fuel in the core, and this needs to be considered when examining retrieval methods. Furthermore, although it is unlikely that the fuel debris that fell to the PCV bottom has spread outside of the pedestal, no investigation has been conducted inside the RPV and outside the pedestal. Thus, a direct video investigation is required in a future study.

(3) Unit 3

- As described in 3.1.2.4 below, retrieval methods are being examined to further expand fuel debris retrieval ahead of other units. From FY 2022 onward, the actual site applicability and technical feasibility should be studied for the issues and risks to be examined in greater depth.

- Previous PCV internal investigations (inside the pedestal) revealed that the control rod drive housing support has partially fallen and deformed, several structures have fallen on the lower part of the pedestal, including structures presumed to be structures inside reactor, and that there are deposits assumed to be fuel debris. According to muon surveys and analyses, it is estimated that a larger amount of fuel debris than in Unit 2 may have fallen into the pedestal and spread out of the pedestal through the worker access opening. In order to improve the reliability of the methods to be selected, it is necessary to consider survey planning to observe the distribution of deposits outside the pedestal, consider additional investigations in the pedestal and the RPV and incorporate these investigation results into the examination and design of the methods.

- When examining retrieval methods, it is necessary to examine containment facilities considering the damage to the reactor building.

(4) A common strategy for each unit

- The PCV internal investigation of Unit 1 confirmed that the pedestal was partially damaged. However, in past research and development, it was confirmed that its supporting function was not significantly impaired in the seismic evaluation assuming the extent of the damage. Along with expanding knowledge through internal investigations, it is also necessary to discuss the events during the accident, assumed from the fact that hot deposits (fuel debris) flowed out of the pedestal. Based on these discussions and knowledge, removal methods of deposits inside and outside the pedestal and the possibility of deposits flowing into the S/C should be examined, while incorporating the findings gained from internal investigation into fuel debris retrieval methods, including for other units.

- Information about the inside the PCV of each unit obtained so far is limited, and there are many areas where direct video information is not available. Therefore, additional internal investigation of the PCV and RPV of each unit should be considered to promptly collect more information, including the condition of the damage at the RPV bottom and the presence or absence and distribution of deposits outside the pedestal. Gaining such information at an early stage enables verification of the direction of the fuel debris retrieval strategy to be pursued in the future, leading to engineering with less regressing.

- After analyzing and clarifying the causes of a number of on-site problems experienced in the on-site decommissioning work to date, improvements should be made, including in the organization and structure, and consideration should be given to incorporating measures to prevent recurrence into the next phase of the work. Planned fuel debris retrieval requires development of a method that can eliminate the potential risks based on these experiences, and for risks that cannot be eliminated, preparing a response plan if these occur in advance.

- Fuel debris retrieval, including preparatory work, will be executed in a high-dose, severe site environment. Although remote devices are used under various circumstances, workers will have many on-site operations to reduce radiation dose on-site, prepare for the removal of the existing structures, and prepare and arrange equipment for use. The maintenance of remote devices and restoration in case of failure also need to be considered. It is necessary to examine methods considering the entire field work sequence from preparation to retrieval and select methods that enable retrieval even if all on-site conditions cannot be identified and methods (robust method) not easily affected by external events such as earthquakes.

- Although the amount of remaining fuel debris differs, it is assumed that fuel debris exists in the RPV of each unit. Therefore, in the partial submersion method, using side-access only, which is considered to have limited access to the inside of the RPV, is not sufficient to cope with the situation, and top-access is also required. Therefore, it is considered essential to accelerate the development and engineering of the top-access method again and then examine the fuel debris retrieval method using a combination of top and side access methods. From this perspective, examinations will be made on the methods, operation procedures, shielding systems and cell structures to be installed on the operating floor, fuel debris and waste transfer flow, and classification of contamination control.

3.1.2.2 Development status and prospects of trial retrieval (internal investigation and fuel debris sampling)

For the trial retrieval (internal investigation and fuel debris sampling) in Unit 2, the operation will be performed by opening the flange of the penetration X-6 to make a larger opening than before, through which the robot-arm is moved in/out to retrieve fuel debris inside the PCV. In this operation, an expansion will be made to provide an isolation chamber to be built during opening the penetration X-6, and an enclosure to be newly provided, since the conventional containment barrier was located in the close flange part of the penetration X-6. Although small in scale, this is a fundamental form of site construction for future retrieval work, in which an opening will be newly provided in the PCV to extend the containment barrier outside the PCV. This presents an approach that enters a new stage.

As described above, trial retrieval (internal investigation and fuel debris sampling) is entering a new phase, and the series of work described below should be carried out in a phased manner (See Fig. 7). Moreover, due to the uncertainty of the conditions inside the PCV, it is necessary to proceed with the work safely and carefully, bearing in mind that additional work or rework may be required depending on the actual on-site situation and that the work may not go as planned. Furthermore, each of these operations has no precedent, and it is very important to utilize the valuable information, experience, etc. gained through them in subsequent retrieval operations. In addition, it is important to consider in advance troubleshooting and a system for a prompt response to go with it.

(1) Preparatory work (completed)

[1] Environmental improvement around the penetration X-6 in the reactor building

[2] Hole diameter enlargement of the penetration X-53

(2) Installation of an isolation chamber (isolation room inside stage, hatch isolation room, robot carry-in room) (in progress)
(3) Opening of the penetration X-6 hatch by hatch releasing apparatus
(4) Removal of deposits in the penetration X-6 by deposit remover
(5) Robot arm installation (removal of the robot carry-in room, installation of the penetration X-6 connection structure, extension pipe, and enclosure)
(6) Robot arm entry (penetration X-6 - CRD opening - inside the pedestal), surrounding check, and removal of obstacles (Abrasive water jet)
(7) Internal investigation and fuel debris sampling by robot arm
  [1] Internal investigation from the PCV inlet to outside the pedestal
  [2] Internal investigation inside the pedestal (above the grating, PCV bottom, etc.)
  [3] Sampling from the inside the pedestal (sampling from above the grating and PCV bottom, etc., is under consideration)
(8) Storage to shipping containers from fuel debris retrieval equipment, and dose measurement
(9) Acceptance into glovebox and measurement
(10) Removal of containers, storage in shipping containers, and carry-out
(11) Off-site transport and off-site analysis (analysis of fuel debris properties)

Regarding preparation status of trial retrieval (internal investigations and fuel debris sampling), it is expected that the production and installation of the required devices, site preparation, and installation of glovebox for transporting retrieved fuel debris will be completed, workers including operators of various equipment/devices required for retrieval and on-site leaders will be secured, and the framework for verification tests, mock-up tests, training, and retrieval will be established by the end of Phase 2 of the Mid-and-Long-term Roadmap.

Verification tests of the newly developed robot arm were conducted in Kobe (Kobe Shipyard & Machinery Works, Mitsubishi Heavy Industries) from July 2021 until January, 2022, following verification tests at a factory in the UK. Since February, verification tests (mock-up tests) have been conducted in an actual simulated environment using the mock-up facility at the Naraha Center for Remote Control Technology Development (JAEA), which covers the entire PCV from the penetration X-6 and beyond.

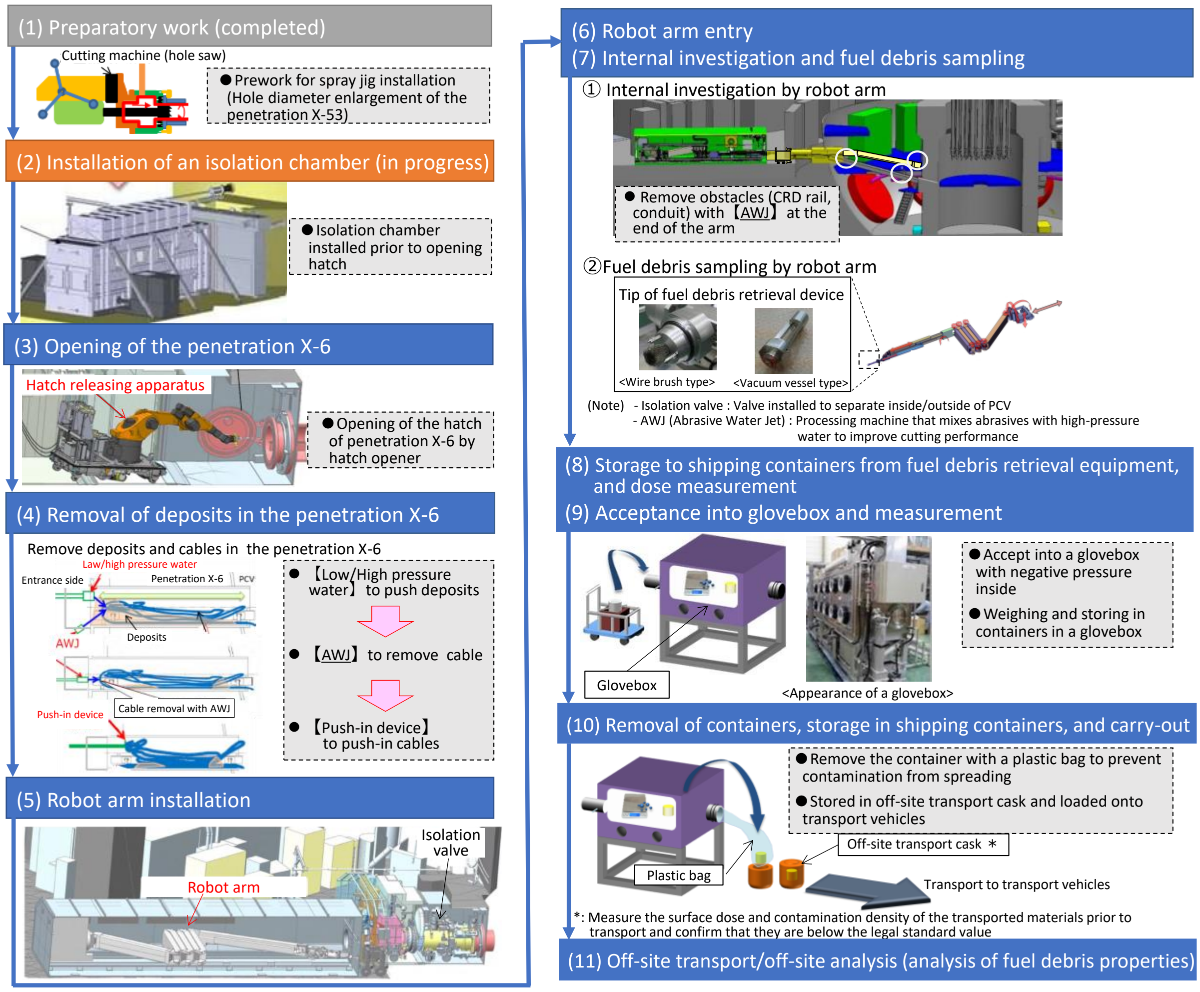
It is important for on-site applications with uncertainty to ensure functional verification checks under various conditions and equipment can be rescued in case of emergency. Therefore, it is necessary to make the preparations needed, ensure that the required functions are satisfied by conducting mock-up tests that simulate the actual site even if it takes time, and ensure that newly identified risks are eliminated. This process needs to be reiterated when necessary. For example, mock-up testing at the Naraha Center for Remote Control Technology Development, progress is underway to modify and verify control software and improve some equipment, both of which became additionally required based on the results of verification tests in Kobe and in the UK.

Moreover, the plan is to expand one-through testing for higher reliability. Furthermore, it is necessary to thoroughly prepare the measures required for the practical application, not only by simulating severe environments on site in mock-up testing, but also by making clear any areas that are not simulated.

In constructing the access route on-site, the installation of the isolation chamber has been delayed due to the unevenness of the floor at the location of the isolation room inside stage and airtight leakage-proofing in the hatch isolation room, etc. After installation of the robot isolation chamber is completed, the plan is to open the hatch of the penetration X-6, remove deposits inside the penetration X-6, and establish the penetration X-6 connection structures and the enclosure (with a built-in robot arm, etc.).

During the installation of the isolation chamber, leakage from the newly installed in-stage isolation chamber was observed in an airtight leak test (leakage from rubber containment barrier). This event reaffirmed that expanding the containment barrier outside the PCV, which interfaces with the existing structures in a high-dose environment, would be a challenging task. It was also reaffirmed that since heavily equipped workers need to be replaced in a short time for operations in a high-dose environment, it is always necessary to ensure quality and safety in performing work. Moreover, in the future, when the installations of apparatus such as the robot arm system that are interfacing with the existing structures outside the PCV to extend the containment barrier, it will also be a challenging task in a high-dose environment. Thus, careful preparation based on this event will be necessary. In addition to the above, paying full attention to the unique characteristics of Fukushima Daiichi NPS, such as the fact that containment barriers are imperfect and uncertain, and that earthquakes are expected to occur in the future, work descriptions should be reviewed again and operation training should be provided to enhance future work safety and reliability. It is also necessary to incorporate above features, knowledge and experience gained this time into examining fuel debris retrieval methods after the gradual expansion of the retrieval scale.

Given the above events, equipment should be deployed on-site after sufficient performance and operational verification.



(TEPCO material edited by NDF)

Fig. 7 Work steps of trial retrieval (internal investigations and fuel debris sampling)

The key technical issues, countermeasures, and points to consider are described below.

・ Dust dispersion prevention associated with removal of deposits in the penetration X-6.

In light of a dust dispersion event caused by an abrasive water jet (hereinafter referred to as “AWJ”) to construct access routes for PCV internal investigation in Unit 1, measures such as removal of deposits by low-pressure water cleaning, and dispersion control by spray curtains have been prepared to prevent dust dispersion due to removal of deposits inside the penetration X-6. It is confirmed that due consideration has been given to safety measures in the operation procedures (e.g., prior understanding of dust behavior by test injection, segmentation of cutting work), which take measures to control dust dispersion into account, such as monitoring dust concentration and gradually expanding operations. While placing the highest priority on ensuring safety, discussions will be held with TEPCO on setting an appropriate operational value for dust concentration control that will not significantly extend the process due to operation constraints.

・ Considerations for the risk of re-spreading impact of the COVID-19 infection

For the performance confirmation test in Naraha Center for Remote Control Technology Development, it is essential to support by the UK engineers, and it is necessary to maintain the backup system on the UK side in the event of a defect, while sharing information and communicating smoothly with the UK engineers.

It is also important to make all possible preparations for the risk of the COVID-19 pandemic re-expanding in Japan. NDF will confirm these responses.

・ Considerations in project management

It is important to proceed with the project while paying attention to the process progress management of the contractors including overseas enterprises and subcontractors. As part of their project management activities, TEPCO needs to make further efforts to perform prior-evaluation of risk of delays, and develop alternative plans and measures to prevent the occurrence of risks. NDF also participates in meetings with contractors and their subcontractors to closely check the status and support risk assessment.

・ Limitations in the scope of trial retrieval (internal investigation and fuel debris sampling) and incorporation into gradual expansion of the retrieval scale

In the PCV internal investigation using a robot arm, it is planned to ascertain the state of existing structures, and the distribution of deposits inside the pedestal (3D data), the distribution of gamma rays and neutron counts at the bottom and on the platform, in as wide a range as possible. However, since more structures and platforms in the pedestal remained than the initial design plan, the range in which the robot-arm can access the bottom of the pedestal is limited. Thus, the possible range of neutron measurement and trial retrieval from the bottom of the pedestal is limited.

Incorporating the results of the arm/tool combinational test in Naraha Center for Remote Control Technology Development, the scope and type of data to be acquired by neutron sensors, 3D scanners, gamma sensors, etc., and the evaluation method of the conditions inside reactor (e.g., fuel debris distribution) based on such data are planned and prepared in advance.

Assuming that fuel debris at the bottom of the pedestal cannot be retrieved, it is also planned to retrieve the deposits on the platform which are highly likely to be fuel debris, as same as those at the bottom of the pedestal. Given the limited scope of investigation and trial retrieval, greater consideration is required in advance to determine what information is needed to gradually expand the retrieval scale as a next step for promoting the retrieval work in a reliable manner.

・ Human resource development and technology transfer for the next step (gradual expansion of the retrieval scale)

With regard to the trial retrieval, there are uncertainties and difficulties in the development of the robot arms and the removal of deposits and obstacles due to a limited understanding of the conditions inside the PCV. Therefore, when performing such work, it is necessary for TEPCO and parties concerned to utilize human resources with a wealth of field experience, including those invited from outside as needed, to develop human resources to foster field-oriented perspectives/feelings, and to transfer techniques cultivated through these activities.

3.1.2.3 Development status of gradual expansion of fuel debris retrieval and further prospects

The retrieval equipment to be used for gradual expansion of the retrieval scale will be improved by increasing the payload capacity and enhancing accessibility while complying with specifications of the devices for trial retrieval (internal investigations and fuel debris sampling).

From the perspectives of research/development and engineering by TEPCO, and in terms of ensuring actual site applicability and safety, NDF continues to observe and check the status of technology development and preparations for application to the site in a timely manner.

The key technical issues and countermeasures are described below.

- Ensuring containment performance of enclosure for fuel debris

In the retrieval operation, the process is repeated from carrying fuel debris retrieved from the PCV into the enclosure, storing in unit cans and carrying out to the outside of the enclosure for on-site transportation. As a result, the enclosure gradually becomes contaminated, and it is important to secure the containment performance of the enclosure.

This work is performed by controlling the pressure in the enclosure as the robot arm is moved in/out. Therefore, in order to confirm airtightness performance and operation reliability, through the duration, it is important to perform prior mockup test, post-installation test of the equipment, and subsequent abnormality monitoring.

- Ensuring reliability of a manipulator

The manipulator to be installed in the enclosure plays an important role in performing various operations and maintenance in the enclosure, and thus it is important to ensure its reliability. Therefore, it is necessary to improve the reproducibility of work through a wide range of operation/maintenance training in advance, and to train operators.

- Ensuring maintenance of devices and countermeasures during the in-service period

To expand the retrieval scale in a gradual manner, in addition to periodic maintenance, repair or replacement is required in case of failure. Since the radiation dose in the Unit 2 reactor building, where the enclosure will be installed, is high and it is difficult to perform maintenance in that place. Therefore, it is planned to construct a maintenance building outside the building, transfer the equipment or enclosure itself, and decontaminate, dismantle, repair or replace it inside the maintenance building. In addition, since the manipulator that performs various operations may require repair or replacement during the in-service period, a device for carrying out the manipulator to the maintenance building is under development.

Since it is extremely important to ensure the maintenance of equipment/devices and their measures, including repairs, NDF will check the examination and preparation status for them in

TEPCO. It is also important to leverage the experience gained through the in-service maintenance of equipment/devices for further expansion of the retrieval scale in scale. Therefore, a system that can reliably preserve maintenance records, including failure histories and their measures, should be established.

- Points of attention in detailed design, manufacturing, and installation of temporary storage facilities

The basic and detailed design of the temporary storage facilities is being undertaken by several companies. Furthermore, installation requires process adjustments, including eliminating interference with the existing systems in advance and avoiding congestion with other operations. In installation work, construction work and equipment installation, including cells, may be conducted almost simultaneously. Thus, design and installation involve a great deal of interfacing, and TEPCO is expected to perform project management by managing processes and resolving pending issues. Even though construction management for designing, manufacturing, and installing these temporary storage facilities is small in scale, many companies are involved, and it is necessary to proceed with construction according to the schedule while adjusting the specifications and interfacing. We believe the experience and knowledge gained from this construction work will be helpful in project and construction management for further expansion of fuel debris retrieval in scale in the future. Even though a wide range of problems might occur, it is important to keep records of them, including their solutions, and leverage the experience in subsequent work.

The plan is to use manipulators and remote devices for operations in receiving/delivery cells and temporary storage cells. It is important to thoroughly check the work details using these devices at the design stage, identify potential risks, and examine and implement countermeasures against them. It is also essential to verify the design and perform mock-up test/training by referring to the knowledge and experience of remote devices in the preceding PCV internal investigation and trial retrieval.

3.1.2.4 Further expansion of fuel debris retrieval in scale

Toward further expansion of fuel debris retrieval in scale, methods should be examined based on the viewpoint that “fuel debris retrieval is an important process in decommissioning, and its retrieval in a reliable manner affects the success/failure of the decommissioning project,” and from a comprehensive standpoint (in anticipation of technical feasibility as well as business continuity). In addition, TEPCO should take responsibility for examining the methods to be used. Therefore, this section describes in detail the procedure for developing methods.

At the Fukushima Daiichi NPS, where uncertainty still exists, the uncertainty of the condition inside the PCV hinders examination, which forces preconditions to be set to perform examination. In judging technical feasibility in the future, it is important to clarify and examine the requirements (boundary conditions) and constraints (site use area, existing system interface, etc.) for methods and systems, including criticality control, dust containment, shielding, and heat removal.

TEPCO is currently conducting a conceptual study on further expansion of fuel debris retrieval in scale, starting with Unit 3, and examining scenarios and methods for fuel debris retrieval. In this process, retrieval methods were examined by the end of FY 2021. However, many challenging issues and risks have been identified for each discussed method. Therefore, from FY 2022 onward, the actual site applicability and technical feasibility associated with these issues and risks will be verified. Since there may be cases resulting from the above verification where the predetermined criteria cannot be satisfied, other methods should also be considered.

The following are the points to be considered for examining retrieval scenarios and methods.

・ Development of retrieval scenarios

In examining methods, based on the five guiding principles (safe, proven, efficient, timely, and field-oriented), a determination should be made not only to satisfy the target safety level but also to use attributes (evaluation items) such as cost and schedule as decision indexes. At the initial stage of the study, it is necessary to quantify these evaluation items as much as possible using multi-attribute decision analysis (hereinafter referred to as “MADA evaluation”) and other methods, and it is most important to clarify decision indexes and criteria. Setting these evaluation items requires clarifying in advance information (e.g., exposure assessment report, strength calculation report) for objectively determining whether the criteria are met. As for the results of examining the methods, it is also important to make efforts to disseminate information in a careful manner so that the evaluation results will be widely accepted by society.

Given the limited understanding of the situation in the PCV, it is important to examine several scenarios of fuel debris retrieval by each unit and to clarify several paths from start to completion. The intention of this study on fuel debris retrieval scenarios is to estimate in advance different results obtained from PCV/RPV internal investigations or technical studies in the future and then conduct an examination based on the preconditions of using such results.

After reviewing these numerous paths, it is important to narrow down promising candidates for retrieval methods at a certain point of the path, and then further narrow down the path to take according to the information obtained afterward.

・ Clarification of requirements

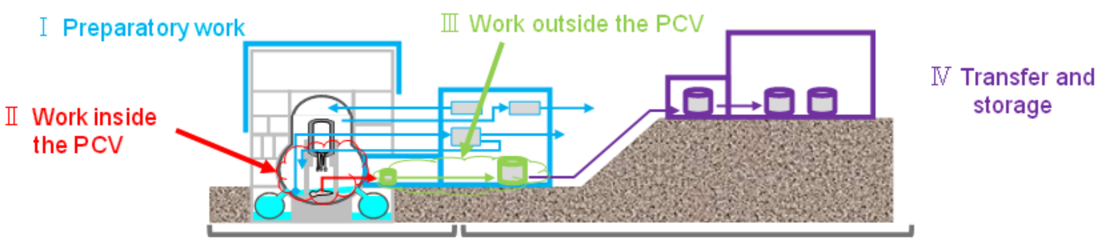
With regard to further expansion of fuel debris retrieval in scale, the methods will be considered, including those for containment, transfer, and storage of fuel debris, based on the findings from fuel debris retrieval in Unit 2 (trial retrieval, gradual expansion of fuel debris retrieval), PCV/RPV internal investigation, research and development and the on-site environment improvement, etc. In doing so, operations, devices and equipment, and facilities will be larger than, and the scope of construction will be wider than in the case of retrieving fuel debris from Unit 2. Therefore, much more attention should be paid in overviewing the entire Fukushima Daiichi NPS, including other work. In addition, in light of the high radiation dose on-site, the limited understanding of the situation inside the PCVs, and the extensive scope of work, it is important to specify the requirements (containment, criticality, operability, maintainability, throughput, etc.) required for operations and devices even more clearly and proceed with the work. Attention should also be paid to the interaction between the requirements.

The following describes the status of TEPCO's examination on the methods and NDF's view on the matter.

- Specific procedure and approach for examining retrieval methods

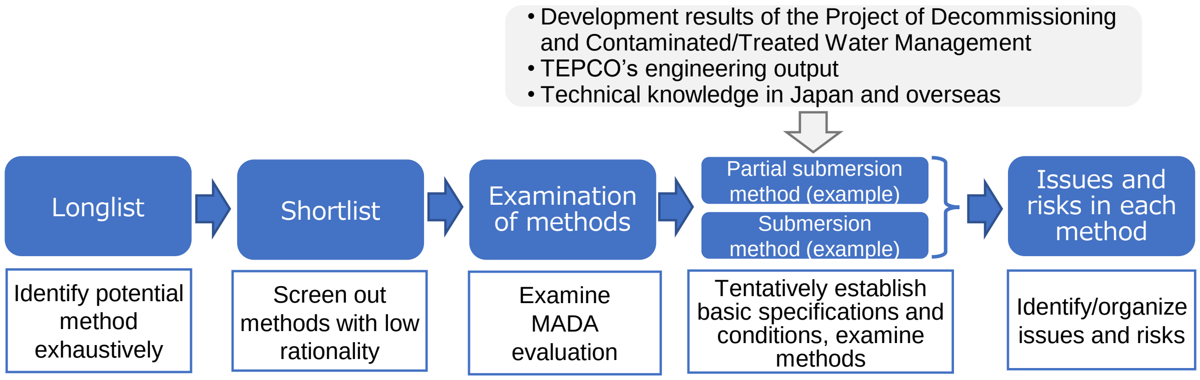
Followings are the works implemented in FY2021. In examining methods, the work process was roughly divided into two processes, the retrieval process, and the transfer/storage process. The retrieval process was further divided into preparation work and work inside the PCV. The transfer/storage process was divided into work outside the PCV and transfer/storage work. This means there were four major work phases, Phase 1 to Phase 4 (See Fig. 8). To examine methods by work phase, the potential methods for each work phase was identified exhaustively, not ruling out any possibilities (setting a longlist), and then methods with low rationality was screened out (organizing a shortlist). Next, each of the shortlisted methods was scored by MADA evaluation. The basic specifications and conditions of these discussed methods were tentatively established to examine methods by incorporating the development results of The Project of Decommissioning, Contaminated Water and Treated Water Management, TEPCO's engineering output, and technical knowledge in Japan and overseas, and then issues and risks were identified and summarized (See Fig. 9). In parallel with TEPCO's examination of methods, NDF is also independently examining them, and TEPCO and NDF are mutually confirming their approach to the examination results and exchanging opinions.

【Retrieval process】		【Transfer and storage process】	
Phase Ⅰ Preparatory work	Phase Ⅱ Work inside the PCV	Phase Ⅲ Work outside the PCV	Phase Ⅳ Transfer and storage
・Reuse, decontamination and dismantling of existing facilities ・Establish PCV access route ・Introduce safety system and facility ・Install debris collection and processing equipment ・Install monitoring and control device	・Handling and collecting of fuel debris ・Cutting and downsizing ・Transport collected debris out of PCV, Separation of solid and liquid ・Maintenance of collection equipment	・Construct fuel debris and related facilities ・Handle, sort and separate collected fuel debris ・Characteristic evaluation of fuel debris ・Processing of fuel debris (drying) ・Load and seal container for transferring to interim storage facility	・Construct interim storage facility (in 1F site) ・Transport packed debris to interim storage facility ・Receive and load container at interim storage facility ・Operation, monitor and maintenance of interim storage facility



(TEPCO material edited by NDF)

Fig. 8 Conceptual diagram of each work phase (a division of process)



(TEPCO material edited by NDF)

Fig. 9 Examination flow for retrieval methods in FY 2021 (outline)

・ Status of examining retrieval methods

[Retrieval process (preparatory work, work inside the PCV)]

In the retrieval process, methods are classified according to the work environment, access direction, and primary boundary. The partial submersion and submersion methods were on the discussion table. This partial submersion method does not use the top or side access method alone but combines them, which has been examined previously. (See Fig. 10 for a conceptual drawing of the current partial submersion method)

On the other hand, the current submersion method differs from the conventional concept of submersion, as shown below. Although the conventional submersion method (fill the PCV with water: PCV submersion method) had advantages in the radiation shielding effect, it was determined to have low feasibility given the technical difficulty of sealing the water in the upper part of the PCV and the radiation exposure during work (see Fig. 11 for the conceptual drawing of the conventional submersion method (PCV submersion method)). For this reason, the previous retrieval policy in Mid-and-Long-term Roadmaps 2017 and 2019 focused on the partial submersion method and it was planned to examine the submersion method again sometime in the future based on R&D progress. Unlike the PCV submersion method mentioned above, this submersion method uses a new idea to submerge the reactor building by enclosing the entire reactor building with a new structure called a shell structure[2] as a boundary. (See Fig. 12 for a conceptual drawing of the current submersion method (shell method))

[2] Shell structure: A shell structure is a structure in which stiffener (a framework that holds deflection) supports the force applied by the plate (surface) and it is used in ships and airplanes.

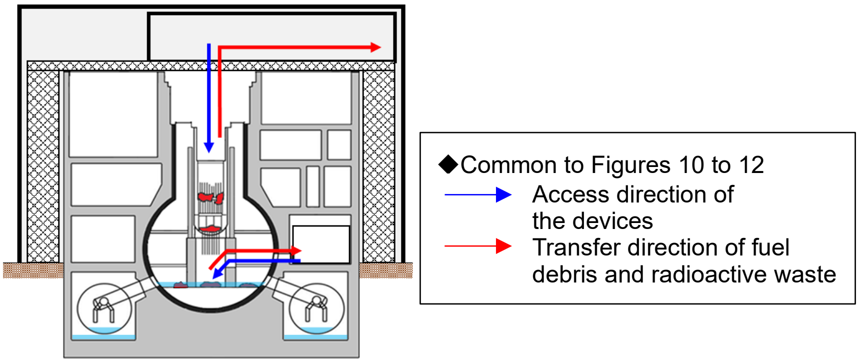


Fig. 10 An example of partial submersion methods
(Conceptual drawing of combination of top and side access)

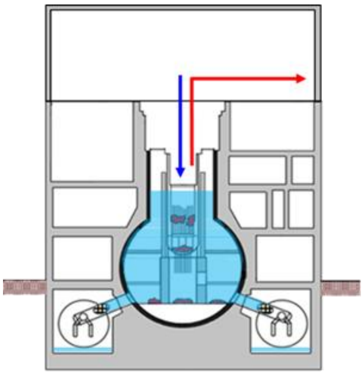


Fig. 11 Reference : Conventional submersion method
(Conceptual drawing of the PCV submersion method)

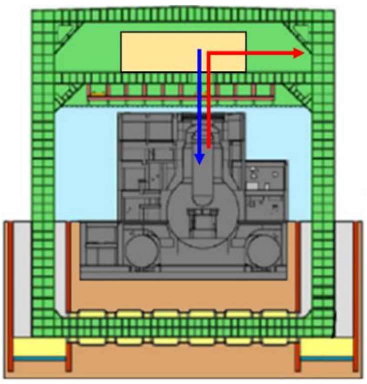


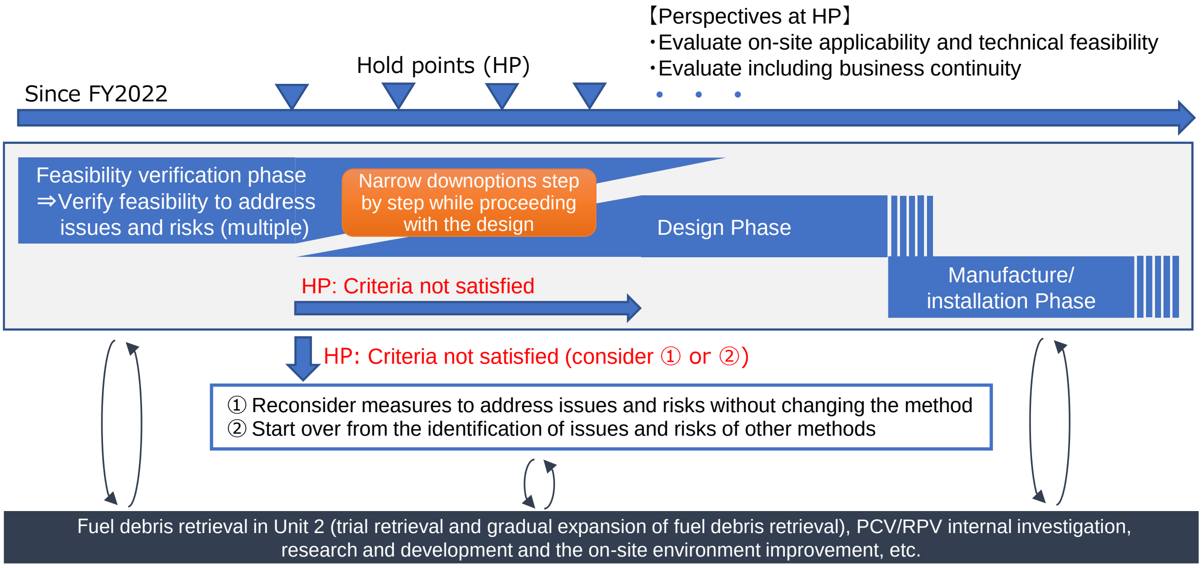
Fig. 12 An example of submersion methods
(Conceptual drawing of shell method)

Since then, the partial submersion and submersion (shell method) methods have been examined. However, both methods have no proven track record in the nuclear industry, and many challenging issues and risks have been identified.

Since FY 2022, the feasibility of each method will be examined. Since there are several possible countermeasures against issues and risks, the options will be narrowed down step by step while proceeding with the design once the feasibility has been confirmed to some extent. In addition, hold points should be established to evaluate on-site applicability, technological feasibility, and business continuity such as cost and construction schedule. If the criteria are not satisfied, it is necessary to consider ① or ② below. As described above, other methods should also be considered (See Fig. 13).

① Reconsider measures to address issues and risks without changing the method.

② Start over from the identification of issues and risks of other methods.



(TEPCO material edited by NDF)

Fig. 13 Conceptual diagram of how to proceed with examining methods after FY 2022

[Transfer and storage process (work outside the PCV, transfer and storage)]

For the transfer and storage process, the methods are classified according to fuel debris processing, fuel debris/waste separation, container, hydrogen management, storage shielding, etc. Each option was evaluated as having no significant difference in terms of feasibility.

Since FY 2022, giving priority to the study of the retrieval process, examinations have been made in terms of connectivity with the transfer process.

・ Toward initiatives for FY 2022 and beyond

As described above, from FY 2022 onward, it is necessary to systematically verify the on-site applicability and technical feasibility to address the issues and risks. Therefore, it is necessary to promptly establish engineering planning for this study and reliably promote management, including checking and reviewing output. To promote this, it is necessary to secure sufficient TEPCO personnel and proceed with the study under a robust TEPCO project framework. In addition, since there are many items to be considered, it is essential to prioritize the issues with a high impact on the feasibility of the method, perform checks and share information at hold points with responsible personnel in each area (e.g., safety/radiation exposure dose, structure (seismic), retrieval method, system, criticality, waste). For this purpose, the TEPCO/NDF review structure needs to be clarified and further strengthened. Moreover, in examining methods, not only technical feasibility but also business continuity, such as cost and construction schedule, should be taken into account from a comprehensive perspective.

Issues in each technical field for further expansion of fuel debris retrieval in scale are described in 3.1.2.6.

3.1.2.5 Continuation of accident analysis activities (clarification of events that occurred at the accident and the process of accident progression)

Analysis of deposit samples collected by the previous internal investigation for fuel debris retrieval is in progress. The information obtained by such investigation and analysis is directly incorporated into fuel debris retrieval methods and storage management. Moreover, examination and study in light of the accident history will promote understanding of phenomena, contribute to studying the cause of the accident and decommissioning, and indirectly to the improvement of nuclear safety.

TEPCO and the JAEA are cooperating in implementing activities for estimating and verifying individual events that occurred at the accident, including overheating, melting, chemical reactions and hydrogen explosions, the process of their progression over time, the operation status of emergency cooling, depressurization equipment, and the amount of combustible gases generated from cables, etc., by comparing the results of sample analyses with mock-up testing on accident progression and past scientific knowledge. Moreover, TEPCO is carrying out independent investigations of the operating floor, and standby gas treatment system, (hereinafter referred to as "SGTS") and so forth in each unit.

The Secretariat of the Nuclear Regulation Authority (NRA), which is responsible for continuing accident investigations/analyses, established the “The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station” to discuss accident analyses and investigate the operating floor in Unit 2, the inside of the reactor building in Unit 3, and SGTS filter trains, etc., with cooperation from TEPCO according to the situation, and compiled these results in an interim report. Based on these investigations, the NRA has assessed that a large amount of Cs exists between the first and second layers of the shield plug installed on the operating floor in Units 2 and 3. Additional dose measurements in the holes bored in the shield plug of Unit 2 and geometry measurements for deformation of the shield plug were also made.

In addition, the information necessary for accident analyses is affected by decommissioning work, such as facility dismantlement. At the same time, there may be cases where efforts for accident analyses interfere with decommissioning work and other operations. As such, the NRA established the Liaison Council on accident investigation of Fukushima Daiichi Nuclear Power Station, for communication and coordination of accident analyses and decommissioning between the NRA, Agency for Natural Resources and Energy, TEPCO, and NDF. An example of managing both decommissioning work and accident investigation, in the partial removal of SGTS piping in Unit 1 and Unit 2, TEPCO is planning to take measurements of the radiation dose rates and with a gamma cameras, and to collect piping samples for analysis after cutting. As a countermeasure against releasing radioactive dust during cutting, injection of urethane foam started in September 2021 to improve the cutting process by checking the injection point of urethane foam with a camera and a laser pointer. Care is being taken to ensure that decommissioning work and accident investigations do not affect neighborhood residents or the environment.

In addition to accident investigation activities in Japan, as an international forum on accident progress and fuel debris analysis, projects of the Organization for Economic Cooperation and Development/Atomic Energy Agency (hereinafter referred to as "OECD/NEA.") have been implemented since 2012. Following BSAF and BSAF-2, the FACE project, which integrates PreADES and ARC-F, was launched in July 2022. 23 organizations from 12 countries are participating in this project, and details are described in Chapter 4.

TEPCO is also planning to systematically conduct on-site investigation while estimating the state of the reactor cores and PCVs, and discussing unsolved issues. After a lapse of about 11 years since the accident, the radiation dose has decreased due to the decay of fission products (hereinafter referred to as "FP") and environmental improvements on site, and accessibility to the reactor buildings has improved. However, there are still many places with high radiation doses. In order to locate FP released at the accident with a low radiation exposure dose, it is important to collaborate with each organization, and continue these activities to a reasonable extent to clarify the events that occurred at the accident, the process of their progression and the equipment operation status. When new facts about the accident are revealed through further investigations and other activities, it is also important to deepen and incorporate knowledge by performing severe accident progression analysis evaluations, etc.

Since the shield plugs are installed on the operating floor, trial retrieval (internal investigation and fuel debris sampling) and gradual expansion of fuel debris retrieval, which is accessed from the first floor of the reactor building, are not directly affected by this. In order to further expand the retrieval scale, however, it is important to examine retrieval methods with decontamination, shielding, and containment in mind, taking into account the possibility that access from the operating floor (top-access) is required with full understanding of high radiation doses on the shield plugs.

3.1.2.6 Technical issues for technical requirements and future plans

The current status and issues of the following items are described below.
(The following is a description of the partial submersion method. Although the submersion method (shell method) was identified as one of the retrieval methods taken up for discussion in section 3.1.2.4, the remaining issues shall be summarized, and a plan for future technological development shall be developed in the process of the feasibility verification of the method against the issues and risks after FY 2022.)

3.1.2.6.1 Technical issues for ensuring safety of fuel debris retrieval work

As for fuel debris retrieval, there are significant uncertainties (unsealed and atypical) in the conditions of fuel debris and containment barriers, and there are safety features such as handling large amounts of fuel debris in incomplete containment. It is necessary to organize an approach to ensuring safety based on these features and to share it with the parties concerned.

Currently, NDF is organizing an approach to ensuring safety with the following as the basis: ① optimization of judgement with safety assessment as its basis ② ensuring timeliness in decommissioning activities ③ complementing design by operating controls, monitoring, analysis, and on-site operation in the event of an abnormality. In addition, along with organizing the concept for ensuring safety, technical requirements have been established for ensuring safety of fuel debris retrieval and intensive studies are being conducted.

3.1.2.6.1.1 Issues in containment functions (gas-phase)

We expect that existing safety systems will be able to cope with the retrieval of fuel debris, such as gripping and sucking, in the case of a trial retrieval or gradual expansion of fuel debris retrieval. The AWJ used to remove obstacles during the PCV internal investigation in Unit 1 caused an increase in dust concentration. Going forward, it is necessary to roll out this experience to similar operations so that they can proceed carefully on a step-by-step basis while the dust concentration is checked. In the subsequent work such as fuel debris cutting, it is necessary to construct the containment function of the gas phase system in consideration of re-scattering of Cs, etc., that adhere to the equipment and structures in the PCV, aerosolization of water containing radioactive materials, and generation of short-lived iodine and noble gases if criticality should occur.

In addition to re-scattering of Cs, etc., the fact that dispersed fine particles (α-dust) containing α-nuclides may be generated and the radioactivity concentration in the PCV gas-phase may increase is a concern. Therefore, dispersion of α-dust from inside the PCV must be suppressed as much as possible, and a function for containing the gas-phases should be provided to make the radiation dose impact on workers and the public fall within the allowable value.

Accordingly, it is reasonable to expand the retrieval scale while understanding the tendency of dust dispersion at each stage of expanding the fuel debris retrieval scale, and verifying the appropriateness of the containment function built in the subsequent stage. In the engineering work conducted by TEPCO, the improvement of dust monitoring installations inside the reactor buildings and the study of decreased or negative pressure in the PCVs using existing equipment are in progress based on the outcome of The Project of Decommissioning, Contaminated Water and Treated Water Management. In the future, the effect on the surroundings will be assessed based on the monitoring results of the changes in condition such as the dispersion of α-dust associated with the work, and the retrieval scale of fuel debris will be gradually expanded. In the process, TEPCO is considering establishing a secondary containment function and studying its necessity through their engineering work, while assuming the possibility of an increasing impact on the surroundings.

3.1.2.6.1.2 Issues in containment functions (liquid-phase)

To mitigate the dispersion rate of generated α-dust and to minimize the transition to the gas phase, fuel debris cutting, etc., would be performed by pouring water over the fuel debris for fuel debris retrieval. Existing safety systems are expected to be capable of fuel debris retrieval by gripping and suction. For the subsequent work such as fuel debris fabrication and removal of obstacles, a large amount of α-particles will flow into cooling water (liquid phase). To prevent the cooling water containing α-particles from leaking into the environment, it is necessary to establish a cooling water circulation/purification system and a liquid-phase containment function in consideration of prevention of the spread of contamination.

For this reason, it is necessary to examine technologies for removing soluble nuclides that may be leached from fuel debris to the circulating cooling water as well as treatment technologies for solid matter trapped by the filter equipped in the circulating cooling water system. Accordingly, The Project of Decommissioning, Contaminated Water and Treated Water Management has been promoting research and development. In parallel with this, the establishment of a PCV circulating cooling system that takes water from the PCV and injects it into the reactor for cooling, which is beneficial in terms of preventing the spread of cooling water containing α particles, was considered in research and development by the same Project.

To establish a reasonable containment function of liquid-phase in each stage of the scale expansion of fuel debris retrieval, it is rational to monitor the radioactive concentration of cooling water by stage and verify the validity of the containment function to be built in the subsequent stage based on the results (information on fuel debris properties, etc.) obtained from research and development by the Project of Decommissioning and Contaminated Water Management. As with the containment function (gas phase), from the viewpoint of verifying/investigating the impact of the retrieval work on the liquid phase, TEPCO, through engineering work, has been discussing system addition/installation, etc., for the purpose of monitoring the circulating water system according to the results of the Project. With regard to the effects on the liquid phase during fuel debris retrieval operations, the scale of fuel debris retrieval will be expanded gradually, based on the results of monitoring changes in the state of waste liquid containing α-nuclides. The water level in the reactor building is required to be maintained lower than the groundwater level to prevent the outleak of cooling water to groundwater and to appropriately control the water level in the PCV. Safety systems are to be established taking this into consideration.

3.1.2.6.1.3 Issues in cooling functions

Fuel debris generates decay heat, for example in Unit 2, the maximum heat generation is still estimated to be several tens kW. The temperature is being maintained below 100°C (cold shutdown state) currently by conducting circulating cooling with water injection into the reactor. In maintaining this cooling function, the technical issues to be addressed for the time being include setting of the target temperature inside the PCV to make each task feasible, as well as the countermeasures to be taken under the assumption of cooling function abnormalities when each task is performed. While essential countermeasures would be to continue cooling by early recovery of the cooling water circulation system or by mobile equipment, etc., it is necessary to evaluate changes in the PCV internal condition based on the time margin in an emergency and to consider emergency response measures and procedures, etc., including collection of devices. In FY 2019, water injection into the reactor was temporarily suspended with the aim of optimizing operation/maintenance management of cooling systems and emergency response procedures, etc. In light of these water injection shutdown tests, from FY 2020 onward, testing will be planned and performed depending on the purpose, taking into account the situation of each unit, for decommissioning in the future. Based on this policy, the amount of water injection in Units 2 and 3 was decreased from 3.0 m3/h to 1.7 m3/h in tests performed in FY 2021 (Unit 2: January to March 2022, Unit 3: November 2021 to January 2022) to gradually lower the amount of water injection. In Unit 3, the amount of water injection was increased to 2.1 to 2.2 m3/h since late June 2022 because the water level continued to drop after the earthquake that occurred on March 16, 2022. Thus, the amount of water injected into the plant may change depending on future conditions. Based on the condition of lowering the PCV water level, the study is underway to determine water injection methods for the future, including further reduction of water injection.

In addition, during fuel debris retrieval operation, the processing of cutting fuel debris while spraying water is conceivable from the perspective of dust dispersion control, and attention should also be paid to water level control inside the PCV, as well as controlling of the contaminated water generated.

From the above, monitoring parameters and their criterion need to be studied and prepared through engineering work in TEPCO in order to carefully promote fuel debris retrieval work while observing how this work will affect the existing circulating water cooling and purification system, as well as its cooling function.

3.1.2.6.1.4 Issues in criticality control

Currently, subcriticality state monitoring based on the implementation plan confirms that no signs of criticality have been observed. In addition, it is assumed that impurities such as in-core structures were introduced during core meltdown caused by melted fuel assemblies. It is estimated that fuel debris were dispersed over a wide area outside the core due to the progress of the accident. Therefore, the criticality of the fuel debris at the Fukushima Daiichi NPS is not likely from an engineering perspective. Even assuming that control rods may melt down before the fuel elements in the course of core meltdown and that the optimum mixing of incidentally crushed fuel debris with water occurs, the possibility of criticality is considered small.

Although the possibility of criticality is considered low, fuel debris retrieval involves an operation that changes the shape of the fuel debris. It is important to plan criticality control based on the shape of the fuel debris, working conditions, and other factors and to establish a reliable control method through prompt detection and shutdown in the case of an unexpected criticality.

In the initial stage of fuel debris retrieval, criticality control is implemented by retrieving fuel debris while limiting the amount of fabrication based on methods that will not significantly change the fuel debris shape, such as gripping and sucking. Also, in the process of expanding the retrieval scale and cutting, measures such as neutron measurement, pre-work subcriticality measurement, and preparation for inserting neutron absorbers will be taken. Reliable criticality control (criticality monitoring) is required that combines design and monitoring by operators with the decision-making process to suspend and resume work.

The retrieved fuel debris will be placed in containers that can maintain a subcritical state and be appropriately stored. In TEPCO's engineering work, the concept design is in progress for circulating water system configurations and system specifications for further expansion of fuel debris retrieval in scale.

3.1.2.6.1.5 Issues in the structural integrity of PCVs and buildings, etc.

As for the main equipment in the PCV/RPV pedestal, etc., and reactor buildings, their structural integrity has been evaluated in post-accident studies by TEPCO and the Project of Decommissioning and Contaminated Water Management. As a result, it has been confirmed that the main equipment and reactor buildings have a certain level of seismic margin.

Hereafter, the existing main equipment and reactor buildings, as well as equipment/systems and buildings (including modified areas of the existing equipment/systems and buildings) to be newly installed for fuel debris retrieval over a relatively long period, should satisfy the functional requirements and (1) be capable of performing operations safely and (2) ensure the required level of safety against external events such as earthquakes and tsunamis. Assuming (3) long-term maintenance management, in addition, it is important to (4) feedback new knowledge to be gained from planned PCV internal investigations and fuel debris analysis results, etc., to the design of fuel debris retrieval systems and the study of retrieval methods.

Moreover, regarding the existing equipment/systems and buildings, lowering of the water level in the PCVs of Units 1 and 3 was confirmed after the earthquakes that struck off the coast of Fukushima Prefecture on February 13, 2021, and March 16, 2022. Although cooling functions were maintained in both earthquakes, in light of both earthquakes, in order to maintain and manage the equipment/systems and buildings with the above functions over the medium-and-long term, it is necessary to conduct impact assessments on the accident impact, aging degradation and external events (earthquakes and tsunamis, etc.) anticipated during the decommissioning period. In view of the fact that the past assessment of these effects was limited, it is necessary to make maximum use of existing techniques and evaluation results for planning and implementing an investigation plan, in which remote control under a high radiation environment is a challenging issue, and to develop underlying technologies to understand the situation. In so doing, while giving priority to safety, it is useful to actively introduce the latest knowledge and achievements not only in the nuclear field but also in other fields. Based on the above impact assessment, it is crucial to prepare for these risks caused by earthquakes or aging degradation expected hereafter. The following discusses preparedness for seismic risk and aging degradation risk.

(1) Seismic risk preparedness

To prepare for possible seismic risks in the future, it is important to specify and implement measures after determining the margin through seismic assessment. In this process, the uncertainty in the on-site environment, the work difficulty, and the workers' exposure should be fully considered.

Seismic assessment needs to consider the impact of the accident and thinning caused by aging degradation in line with the actual situation and set the conditions for examination. However, because of the high-dose environment, the information available is limited, and establishing conservative conditions for examination may increase the difficulty of implementing measures. Therefore, considering that high uncertainties result in moderately conservative conditions, it is also important to work to understand the impact of the accident and the actual state of aging degradation with high accuracy. For example, although the measurable areas are limited, it should be devised to reduce uncertainties in the scope and method of feedback, etc., such as utilizing the measurement results of the corrosion growth rate in piping for estimating locations where measurement is not possible based on model analysis.

In addition, one method for seismic risk preparedness is reducing the stress generated during an earthquake. For example, drainage is planned for the S/C in Units 1 and 3 with a water level higher than during normal operation caused by the accident. In Unit 3, drainage of the main body of the PCV is underway, which is required before drainage of the S/C.

Regarding the reactor buildings of Units 1 to 3, a certain level of safety has been confirmed through seismic assessments that take into account the state of damage after the accident. However, as with the main facilities described above, verification of the seismic safety over a long period during fuel debris retrieval is required.

For this purpose, although it is challenging to perform investigations due to the high radiation dose, continuous investigations should be carried out to observe the condition of the damage, deterioration, and condition of the corrosion.

As TEPCO undertakes the following activities, it is important to accumulate knowledge through ongoing investigations and consolidate information on the condition of the buildings.

- Application of unattended and labor-saving technologies that utilize robots and drones
- Detailed surveillance by core sampling using Unit 4, where detailed assessment is practical
- Installation of seismometers and utilization of observation records

When the above investigation reveals new facts or findings for components considered in the seismic assessment, such as a decline in structural performance or additional damage due to large earthquakes, it is important to update the information on the condition of buildings and incorporate it into the seismic assessment as appropriate.

(2) Aging degradation risk preparedness

Since thinning due to corrosion is assumed to cause degradation of RPVs and PCVs due to aging, the structural strength tends to decrease over time. Possible preparedness can be for the structures themselves and the environment in which they are installed. Generally, measures for the former includes coatings. However, it is extremely difficult considering humans cannot easily approach the structures. Therefore, priority will be given to examining the latter environmental approach. For reactor water injection as ongoing action, measures are being taken to reduce the dissolved oxygen concentration by nitrogen bubbling and hydrazine injection in the tanks. For the gas phase, nitrogen is sealed inside the PCVs.

However, since the PCVs are damaged, and degradation due to aging progresses over time, it is important to implement measures to maintain the low oxygen concentration in the PCVs appropriately and continuously.

As for existing and new equipment/systems and buildings, the loading conditions (layout, size, weight of the new equipment/systems, new openings on PCV/biological shielding walls, etc.) during fuel debris retrieval will be specified with further progress in designing. In order to ensure the structural integrity of equipment/systems and buildings, while considering the state of the site, examination will be promoted steadily based on the latest design information.

3.1.2.6.1.6 Issues in reduction of radiation exposure during work

In accordance with the Mid-and-Long-term Roadmap and TEPCO's Mid-and-Long-term Decommissioning Action Plan, removal of obstacles and radiation dose reduction in the reactor buildings are in progress as improvement of the work environment in work areas/access routes. In preparation for trial retrieval, ongoing on-site radiation dose reduction has resulted in reducing the radiation dose around the aisle on the west side of the first floor of the Unit 2 reactor building and the penetration X-6 in the northwest area to approximately 5 mSv/h or less (average 2 to 3 mSv/h). In the future, as work related to fuel debris retrieval, reduction of exposure during work such as removal of high-radiation dose equipment, etc. is an issue, and research and development has been promoted by The Project of Decommissioning, Contaminated Water and Treated Water Management to support TEPCO's engineering.

The main work areas related to fuel debris retrieval are high radiation dose areas such as inside the reactor buildings. Also, there comes the need to handle nuclear fuel materials containing α-nuclides from fuel debris with a large dose contribution in the case of internal exposure. Accordingly, enhanced control of not only for external exposure but also for internal exposure is essential for reduction of exposure.

With the objective of dose reduction in long-term decommissioning, it is important to accumulate knowledge such as on-site operation experiences and lessons learned and hand down know-how. For further expansion of fuel debris retrieval in scale, it is necessary to share information such as the technique of handling α-nuclides during trial retrieval and allow prompt feedback for the next work plan. Since May 2021, JAEA, which has the knowhow, has been providing guidance in preparation for trial retrieval due to concerns about body contamination and internal exposure risks in handling α-nuclides.

In particular, in fuel debris retrieval operation, access to the PCV should be made from the penetration X-6, etc., after the work environment in the reactor building is sufficiently secured. To reduce the radiation exposure of workers in the reactor building, it is important to conduct sufficient investigations on the radiation dose distribution and state of contamination, including the contribution from the surroundings of the subject areas, to identify the source locations and intensity as much as possible and to build the radiation dose reduction plan. Upon adequate verification on the operation feasibility, the target dose rate in the work areas and access routes shall be set in consideration of the margin for the radiation exposure dose limit for workers specified by laws and regulations. In the radiation dose reduction plan for high radiation dose areas, it is important to take management measures to reduce the total radiation exposure dose to as low as reasonably achievable and accomplish operations with respect to work hours in accordance with dose limits and required work hours to accomplish operations. Based on the above, and as R&D tasks by The Project of Decommissioning, Contaminated Water and Treated Water Management, the development of technologies to identify radiation sources using environmental survey data and to digitize the environment and radiation source distribution visualized by digital technology, for the formulation of safe and efficient work plan has been in progress since FY 2021. This has led to the development in accordance with the required functions. Moreover, in developing remote technologies for environmental improvement and removal of obstacles under high radiation dose, the obstacles to be removed have been selected and the elemental technologies have been extracted in accordance with the required functions, and specifications of remote control device have been studied for engineering implemented by TEPCO based on the results of technical investigation and element test since FY 2020.

It is necessary to formulate a long-term work plan to help reduce the total radiation exposure of workers without concentrating worker exposure on specific individuals, implement holistic and adequate radiation exposure control, and secure workers as human resources from a long-term perspective. Support should be provided to develop a database that can improve the efficiency of work planning and radiation exposure control and establish a system that manages and operates various information on the entire Fukushima Daiichi NPS in an integrated, step-by-step manner.

3.1.2.6.2 Technical issues related to fuel debris retrieval methods

3.1.2.6.2.1 Issues in securing access routes

For carrying in, installing, and carrying out devices and equipment used for fuel debris retrieval work, and transporting fuel debris and waste, access routes should be established by removing obstacles on the access routes and reducing the radiation dose in the R/B to the level at which such tasks can be performed. When establishing new openings in the PCV or the like to construct access routes to fuel debris, suppression of the release of radioactive materials from the PCV and RPV and maintaining the integrity of existing structures should be kept in mind.

The Mid-and-Long-term Roadmap indicates that the first implementing unit would be Unit 2 and trial retrieval begins toward gradual expansion of fuel debris retrieval. Accordingly, TEPCO is currently proceeding with specific engineering studies to conduct an access route from penetration X-6 in Unit 2.

On the other hand, toward further expansion of fuel debris retrieval in scale, studies are underway on the construction of access routes from the side opening of the PCV to fuel debris (the side access method), based on the results of research and development conducted to date by The Project of Decommissioning, Contaminated Water and Treated Water Management. In the side-access method, the issue is to address containment, shielding for connecting structures between newly installed heavy structures and the side-opening of the PCV, and seismic displacement, and technical development of the method is underway using lightweight cells and fixed rails as well as access tunnel systems.

As for the construction of access routes including top access (top-access method), in addition to side access, the technology for removing obstacles and transportation methods that can shorten the preparation processes for retrieval are under study in order to enhance throughput. Since FY 2020, the Project has been examining the feasibility of a method to cut, retrieve and transport interfering structures as a single or large unit while ensuring containment and shielding. TEPCO’s engineering has been studying the overall process of the methods for Unit 3, assuming that it will be necessary to combine side-access retrieval, which provides easy access to the inside and outside of the pedestal, and top-access retrieval, which provides easy access to the inside of the RPV. The NRA pointed out the possibility that a large amount of Cs might exist on the undersurface of the shield plugs of Units 2 and 3 from their evaluation of TEPCO's radiation dose measurements on the operating floor. In this respect, consideration needs to be given to establishing access routes for the top-access retrieval method based on the results of additional investigations in the second half of 2021, including surveys on the situation and radiation doses in the reactor well below the shield plug and radiation dose surveys in the borehole.

In the future, based on the above-mentioned issues, it is necessary to clearly define the access route to be built at the next stage from the data obtained at each phase of scale expansion of retrieval. In particular, when cutting the inner door of the penetration X-2 in unit 1, the dust concentration in the PCV increased more than expected before the start of the work, and the pressure in the PCV dropped while installing a camera chamber for investigating obstacles. Therefore, not only countermeasures to prevent dust dispersion, but also the extra time required for responding to when faced with such an unexpected situation need to be considered and planned.

3.1.2.6.2.2 Issues in development of devices and equipment

In each phase of trial retrieval, gradual and further expansion of fuel debris retrieval in scale, devices and equipment for fuel debris retrieval need to be developed with emphasis on safety, reliability, and efficiency. To flexibly respond to the situation inside the RPV and the PCV bottom where the fuel debris is predominantly present, the specifications of devices/equipment to be developed in these phases should be established in consideration of radiation resistance, dust resistance, waterproofness, range of temperature, remote inspection/maintainability, remote operability, securing visual field, seismic resistance, protection mechanism for collision avoidance or automatic shutdown in case of abnormality, high reliability, appropriate redundancy, a rescue mechanism that does not disturb the subsequent work when a problem occurs, and efficiency of fuel debris retrieval.

Equipment development for trial retrieval and gradual expansion of fuel debris retrieval has progressed as part of research and development of The Project of Decommissioning, Contaminated Water and Treated Water Management. Testing and training of the robot arm and other equipment to be applied to the trial retrieval of Unit 2, which had been underway since 2021, has been completed at the manufacturer's plant. Testing and training are now in progress at the Naraha Center for Remote Control Technology Development from 2022. After the gradual expansion of fuel debris retrieval, TEPCO needs to take over and substantiate the development results. While preparing education/training scheduled to be started from 2021 for the fuel debris retrieval operations using these remote devices. Prior to installing remote equipment such as robot arms on site, adequate performance verification and operation training are essential by using mockups simulating the expected PCV internal environment. For this purpose, examination of mockup systems has been made.

Regarding devices and equipment for further expansion of fuel debris retrieval in scale, the followings are underway: development of the installation methods of access systems and side-access retrieval methods associated with dismantling/removal techniques for interfering equipment in the PCV, and development of top-side retrieval methods for cutting and transporting large equipment and for preventing the spread of contamination. TEPCO is currently conducting a conceptual study to examine methods for further expanding the scale of retrieval. In FY 2021, TEPCO examined retrieval methods to identify issues and risks for each method. Since FY 2022, studies have been conducted on these issues and risks in terms of feasibility. Further development of devices and equipment should be planned and promoted in light of the status of examination of the methods.

As for how to proceed with development, it is necessary to flexibly promote operations in the subsequent phase based on the information gradually obtained from preceding investigations and retrieval work, and to continue development for emerging important issues. The developed devices and equipment need to be combined as a system and undergo a series of mockup tests to demonstrate that they can realize their performance safely and reliably at the actual site. These mockup tests need to be implemented in a facility simulating the on-site environment in order to verify the applicability of remote equipment and operability/maintainability of the entire remote system under severe environmental conditions containing significant uncertainties. Therefore, in cooperation with the organizations concerned, NDF and TEPCO have been engaged in examining how to proceed with the remote mockup test plan, the test plan review, the scope of the mockup facility to be maintained, the time required, and operation management, etc. From FY2021, TEPCO has taken the initiative in promoting examination and materialization.

3.1.2.6.2.3 Issues in system installations and working areas

Assuming that safety functions are ensured, and considering avoidance of excessive system specifications, it is necessary to examine the establishment of system installations, etc., take necessary measures such as system additions based on the results of such examination, and then to operate them properly. In carrying out examination, sufficient areas should be secured to satisfy the required environmental conditions while considering installing shields for reducing radiation exposure for workers in addition to system installation, operation/maintenance management.

The system installations include a negative pressure control system required for establishing containment functions (gas phase), a circulating water cooling and purification system required for maintaining the containment functions (liquid phase) and cooling functions, and a criticality control system required for controlling criticality. Moreover, realization of measurement systems (for pressure, temperature, water level, radiation, etc.) to monitor the PCV internal state is a significant issue, which is essential for fuel debris retrieval. For building of safety systems incorporating the above, prerequisites (system design criteria) are provided tentatively based on the research and development performed by The Project of Decommissioning, Contaminated Water and Treated Water Management, and TEPCO has been examining the system design and layout through their engineering work.

Regarding the gas-phase system, in FY 2021, the preconditions for negative pressure control and the concept of ancillary systems were summarized with a view to the lowered airtightness of the PCV. For the liquid-phase system in the Project, technologies to remove soluble alpha-nuclides and treatment of secondary waste generated by water treatment are under development.

3.1.2.6.3 Technical issues related to safe and stable storage of fuel debris

3.1.2.6.3.1 Issues in handling fuel debris (containing, transferring, and storing)

Before initiating gradual expansion of fuel debris retrieval work, a comprehensive system should be established that consists of a series of steps from containing and transferring to storing of retrieved fuel debris furnished with safety functions such as maintaining subcriticality, containment functions, countermeasures against hydrogen generation, and cooling. Accordingly, examination of the following is being progressed until the end of FY 2021.

- Development of basic specifications for the container, such as overall length in consideration of handling, internal diameter, quality of materials and lid structure in light of work efficiency and maintaining subcriticality, etc., and demonstration of the structural integrity of the container by testing.
- Examination of a practical and rational prediction method of hydrogen generation from fuel debris stored in containers; determination of a vent mechanism for hydrogen gas release on the container lid by using the said prediction method; and establishment of safe transferring conditions with consideration for accumulation of hydrogen gas in transferring casks.
- Development of efficient drying technology applicable to fuel debris in unit cans, and consideration on a drying system using this technology.

Moreover, in reference to the results of these studies, TEPCO continues their activities to materialize the equipment and installations (including canister for temporary storage, receiving/delivery cell, and storage cell) needed for containment, transfer, and storage of fuel debris, which will be retrieved during the gradual expansion of fuel debris retrieval, in coordination with other associated projects. Toward further expansion of fuel debris retrieval in scale, storage locations have been examined based on the usage plan for the entire site, and specific transferring routes and storing technologies/types are also under consideration. This study has focused on granular and mass fuel debris. The pulverized fuel debris generated by fuel debris cutting in a slurry or sludge state in the cooling water circulation system as well as in powder state in the gas management system. Therefore, in line with the progress of this study, examination is underway of methods for safe, reliable, and rational storage of powdered and sludge/slurry fuel debris, as well as the necessary equipment and installations, and it is necessary to progress this steadily.

At present, since the information and knowledge on the properties of fuel debris is limited, the systems and devices/installations will be designed based on conservative assumptions of the properties of fuel debris. In the design of equipment and facilities for containing, transferring and storing of fuel debris for further expansion of fuel debris retrieval in scale, it is important to proceed in a streamlined manner by utilizing various measurement data such as the amount of hydrogen generation and debris properties as well as knowledge and experience of the handling of fuel debris during the operations from receiving of the onsite transport container to the storage facility which have been collected and accumulated during the trial retrieval and gradual expansion of fuel debris retrieval.

The Mid-and-Long-term Roadmap stipulates that the processing/disposal method of the retrieved fuel debris shall be investigated and fixed during the third phase after starting the fuel debris retrieval work.

3.1.2.6.3.2 Issues in sorting out fuel debris and radioactive waste during fuel debris retrieval

In the fuel debris retrieval work, obstacles and structures to which molten fuel are partially adhered will also be retrieved from the PCV in addition to fuel debris in which molten core fuel are mixed with metals and solidified, and compounds (MCCI product) produced by mixing molten core fuel with concrete at the PCV bottom. Furthermore, pulverized fuel debris generated during fuel debris cutting is also recovered. Of these, if substances on which a small amount of molten fuel adheres or is mixed are all stored as fuel debris, it may become an obstructive factor in advancing decommissioning because the scale of facilities and sites for fuel debris storage become larger.

Since it has been determined from the fuel debris properties that special attention and installations/systems for handling and storing are required to maintain subcriticality, it is recommended that fuel debris and radioactive waste be separated based on the measurement results of the amount and concentration of nuclear materials and stored separately (sorting). The following studies were conducted in response to this.

- Consideration of which steps in the operation processes, from retrieval to storage, sorting is feasible to separate retrieved materials from the PCV (fuel debris, structures, etc.) into fuel debris and radioactive waste (consideration of sorting scenarios).
- Investigation of techniques/devices that may be capable of measuring or estimating the amount and concentration of nuclear materials contained in the materials retrieved from the PCV in non-destructive methods (investigation of possible measurement techniques).

Based on these studies, it is currently considered an incredibly difficult challenge of requiring innovative technology development to measure or estimate the amount and concentration of nuclear materials in the materials retrieved from the PCV using non-destructive methods because various materials, including rod components (neutron absorber), are mixed inhomogeneously.

In developing measurement techniques and devices, it is important to understand the measurement errors. Other than major factors affecting measurement errors such as the fuel debris properties, location of nuclear fuel material in fuel debris and the storage condition of them in unit cans or containers, there are many factors affecting errors depending on the techniques/devices itself. The extent of such impact is highly uncertain at present due to a lack of knowledge on the properties of fuel debris. Therefore, in parallel with the accumulation of measurement data and the development of actual measurement devices by iterating actual measurement using mockup fuel debris, etc., it is considered beneficial in terms of R&D cost and time saving to identify factors influencing measurement errors and its strength accumulated by a number of numerical experiments by computer and incorporate the findings such as the extent of influence into the development of the actual measurement technologies/devices. Thus, the impact of various condition of fuel debris with different properties and storage conditions on the measurement errors as well as modifications/improvements (e.g., specifications of shielding materials and their installation location) of measurement techniques/devices to reduce measurement errors can also be examined through numerical experiments by computer. Some positive results were obtained in the examination mainly on the numerical experiments in The Project of Decommissioning, Contaminated Water and Treated Water Management in FY 2021. From FY 2022 onward, in addition to the development of measurement devices based on the analytical approach mainly through numerical experiments described above, it is important to continue and accelerate the development of measurement devices by actual measurement of mockup fuel debris and fuel debris of the Three Mile Island Nuclear Power Plant Unit 2 (hereinafter referred to as "TMI-2".) in parallel, using currently available measurement devices.

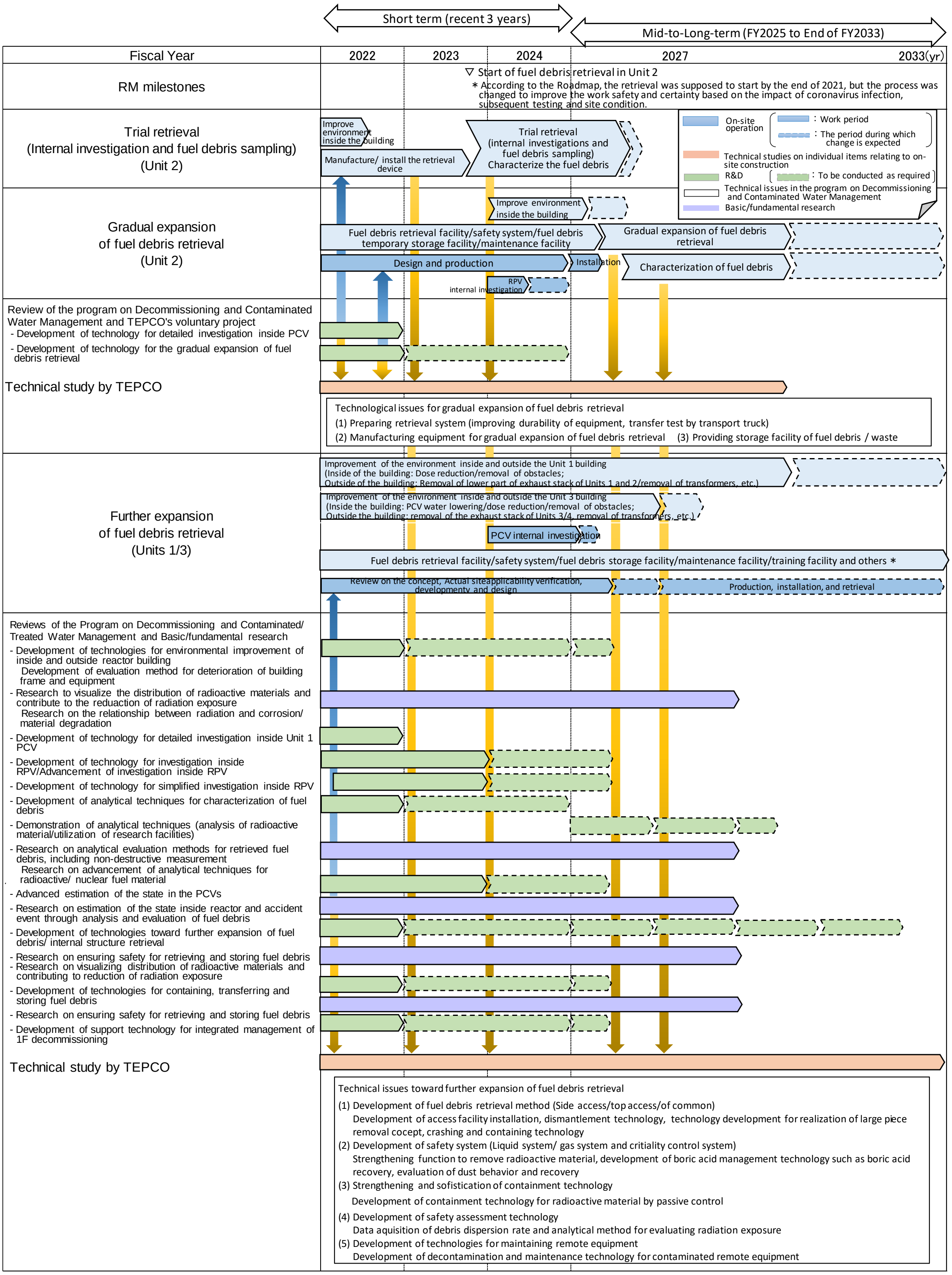
Trial retrieval and gradual expansion of fuel debris retrieval may provide knowledge on actual fuel debris properties through limited sample analysis. Once this knowledge is obtained, it also becomes possible to check whether the measurement results of the non-destructive measuring devices contain significant errors.

It is important to enhance practical applicability and effectiveness of the measurement technologies/devices by continuing the development of them in order to separate (sort) the storage conditions of fuel debris and radioactive waste by such a method.

3.1.2.6.3.3 Issues in examining safeguards strategies

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

The main technical issues and plans described in this section are summarized as shown in Fig. 14.



* It is assumed that Unit 3 will be examined in advance and expanded to Unit 1.

Fig. 14 Technical issues and future plans on fuel debris retrieval (progress schedule)

3.2 Waste management

3.2.1 Targets and progress

(Targets)

(1) The Solid Waste Management Plan (hereinafter referred to as the "Storage Management Plan") is appropriately developed, revised and implemented including waste prevention, volume reduction and monitoring, with updating the estimated amount of solid waste to be generated in the next ten years periodically.

(2) Based on the prospects of processing/disposal methods of solid waste and technology related to its safety (hereinafter referred to as Technical Prospects) presented in FY 2021, creation of options for processing/disposal measures and their comparison and evaluation should be conducted with promoting characterization to establish a waste stream that are suitable for features of solid waste. Proceed study on specific management of the solid waste to present appropriate measures as a whole.

<Key points of "Basic Policies on Solid Waste">

① Thorough containment and isolation

・Thoroughly containment and isolation radioactive materials to prevent human access to them, in order not to cause harmful radiation exposure.

② Reduction of solid waste volume

・To reduce the amount of solid waste generated by decommissioning as much as possible.

③ Promotion of characterization

・Proper characterization addressing an increase in the number of analysis samples to proceed with studies on processing/disposal methods of solid waste.

④ Thorough storage/management

・Generated solid waste should be stored/managed safely and reasonably according to its characteristics.

・Storage capacity should be secured to ensure that the waste can be stored within the site of the Fukushima Daiichi NPS.

⑤ Establishment of selection system of preceding processing methods in consideration of disposal

・To establish selecting methods of processing for stabilization and immobilization (preceding processing) and then select preceding processing methods before technical requirements of disposal are established.

⑥ Promotion of effective R&D with an overview of overall solid waste management

・To establish the continuous operational framework including development of relevant facilities and human resources in order to continue safe and steady solid waste management.

⑦ Development of continuous operational framework

- To establish the continuous operational framework including development of relevant facilities and human resources in order to continue safe and steady solid waste management.

⑧ Measures to reduce radiation exposure of workers

- Thorough implementation of radiation exposure control, health and safety management based on the relevant laws/regulations.

(Progress)

Waste management is a long-term effort that needs to attain the prospect of implementing final disposal, while reducing risks in every stage from generation, storage, processing to disposal.

Since a large amount of solid waste with various characteristics is generated in association with decommissioning of the Fukushima Daiichi NPS, the efforts based on the "Basic Policies on Solid Waste" summarized in the Mid-and-Long-term Roadmap are underway. TEPCO is required to ensure safe and reasonable storage/management of the solid waste generated. Led by NDF, the organizations concerned are promoting efforts based on each role to advance technical examination of integrated measures from characterization to processing/disposal of solid waste. The Technical Prospects were provided in FY 2021 in light of the development results for improving analysis abilities for characterization and establishing a flexible and reasonable waste stream (the flow of the integrated measures from characterization to processing/disposal). The Mid-and-Long-term Roadmap stated that the properties of solid waste would be analyzed, and the specifications of waste form and their production methods will be determined in Phase 3. Therefore, the study was initiated for specific management of solid waste to present appropriate measures as a whole.

The Project of Decommissioning, Contaminated Water and Treated Water Management related to solid waste has been mainly conducted by IRID. However, in preparation for the deadline of the termination of IRID around the summer of 2023, JAEA is taking the main role in the projects which are started from FY 2022.

3.2.1.1 Current status of storage/management in Fukushima Daiichi NPS

To store solid waste properly, TEPCO releases its Storage Management Plan, and estimates the volume of solid waste that will be generated in the next ten years, and shows their policy such as on building waste management facilities to be required based on the volume.

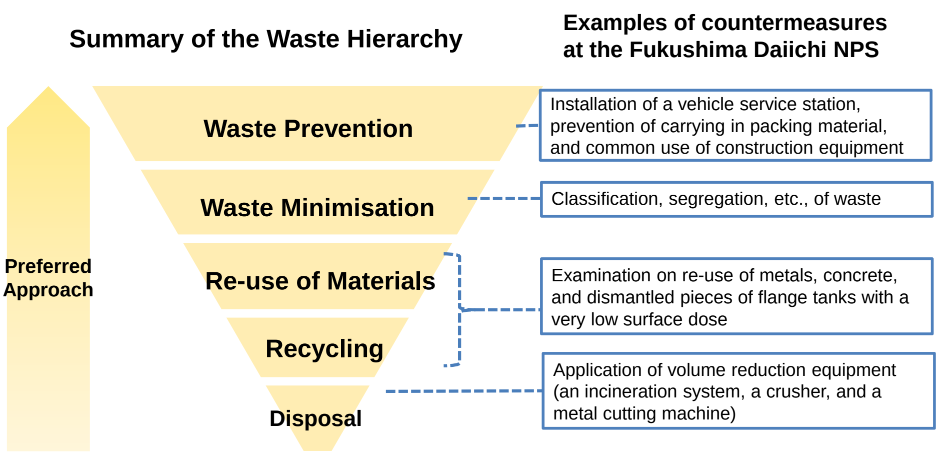
According to this Plan, temporary outdoor storage of the solid waste will be eliminated completely by FY 2028, except for secondary waste generated by water treatment and targets of reuse/recycling. Facilities needed to achieve this goal are under development.

The Technical Prospects have provided the examples of overseas countries that have implemented the waste hierarchy concept (the priorities for measures to be taken as waste management are in the following order: (1) prevention of waste generation, (2) minimization of waste volume, (3) reuse, (4) recycling, and (5) disposal (Fig. 15)). In waste management, it is important to prioritize (1) as much as possible and consider (5) disposal as the last option, and TEPCO has also been implementing initiatives corresponding to this concept.

Among the targets of reuse/recycling, concrete rubble is crushed and recycled as roadbed material after confirming that the surface dose rate is equivalent to the background radiation dose. In addition, such as by melting is under consideration as a decontamination method for recycling metal. The Project of Decommissioning, Contaminated Water and Treated Water Management has also begun to clarify the nuclide distribution behavior during melting and decontamination and examine validation methods after melting treatment as required research and development to achieve the above.

Secondary waste generated by water treatment is planned to be transferred to store in a building, with priority given to sorption apparatus that contain large amount of radioactivity, and a large waste storage building is being constructed as a storage facility for sorption vessels. Moreover, the slurry generated at ALPS (hereinafter referred to as "ALPS slurry") generated by the multi-nuclide removal equipment, etc., and the waste sludge generated at the water purification system (hereinafter referred to as "waste sludge") have high water content and flowability. For safer storage, ALPS slurry will undergo stabilization (dehydration) treatment (Scheduled installation of treatment facility in FY 2024), while waste sludge will be collected from the underground storage tanks in the building, where it is currently stored, dehydrated and then stored into containers, before being transferred to higher ground (starting in FY 2023).

Such solid waste will continue to be generated with some exceptions, and additional solid waste will be generated from fuel debris retrieval.



Source: Strategy Effective from April 2011 (print friendly version), arranged by NDF

Fig. 15 Summary of waste hierarchy at the NDA, UK, and countermeasures at the Fukushima Daiichi NPS

3.2.1.2 Examination of processing/disposal methods

For characterization, examinations are in progress to establish a methodology for developing a medium-to-long-term analysis strategy that defines the solid waste to be analyzed, its priority, and quantitative targets for analysis, etc. Initiatives have begun to use the results of the established simplified and speed-up data acquisition for radiological analysis as standard analytical methods at the Radioactive Material Analysis and Research Facility Building-1 (construction to be completed in June 2022). A field demonstration of techniques to collect sorption from cesium sorption apparatus is in progress to obtain analytical data on high activity waste.

For storage/management, factors affecting filter degradation (blockage/damage) such as hydrogen embrittlement, radiation degradation, etc. and their verification methods were examined and summarized to maintain vent filter functions, which are important as hydrogen generation measures during storage of high radiation-dose waste. Issues during storage and their countermeasures were also examined based on domestic and overseas cases associated with events of concern other than hydrogen generation.

As for the processing technology, the prospect of the application as actual equipment of thermal processing technology to ALPS slurry that has been confirmed through the Technical Prospects. Further, a detailed examination was carried out to control Cs volatilization during processing. While the prospect of the application as actual equipment of normal temperature processing technology was confirmed through full-scale tests, issues related to the transformation of solidified waste and inspection methods for verifying the possibility of solidification are being examined. To contribute to the expansion of technological options, such as expanding the scope of application of normal temperature processing technologies, verification of the applicability of pyrolysis treatment and other interim treatment technologies to detoxifying organic substances, and inactivating reactive/corrosive substances is underway.

Concerning disposal technology, , necessary information and knowledge are being investigated to develop measures that meet the needs of the disposal concept for which review of the waste stream is in progress. Development of a storyboard[3] on the progression of important events in disposal facilities has started for the purpose of identifying critical scenarios for solid waste disposal.

3.2.2 Technical strategy by sectors

In Phase 3, the plan is to determine the specifications of waste forms and their production methods with proceeding characterization of solid waste. Therefore, in coordination among areas of characterization, processing/disposal, a study will be conducted to present appropriate overall measures for specific management approaches for solid waste, while reviewing necessary R&D tasks. Specifically, the first step is to create processing/disposal options for solid waste by examining pending issues related to processing technology, interim treatment, and disposal options. Then, the options will be compared and evaluated using the property data that are becoming clear, and examinations will be conducted to establish a waste stream that is suitable for the characteristics of solid waste.

3.2.2.1 Characterization

It is necessary to improve evaluation of inventory for solid waste and continuously incorporate them into solid waste management, including processing/disposal, while accumulating analytical

[3] Storyboards provide a plain view of the behavior on the entire disposal system and allow for confirming consistency in temporal and spatial scale.

data. In this case, efforts should be made for low-activity waste such as rubble, and high-activity waste such as secondary waste generated by water treatment and waste generated from fuel debris retrieval, according to the characteristics of each type of waste.

For low activity waste, it is not so challenging to perform the analysis work itself. However, it takes an immense amount of time to measure the entire quantity because of the enormous volume of waste. Therefore, efficient analyses and analysis planning methods are needed along with the volume reduction mentioned above. For that purpose, it is important to take an approach that efficiently ensures the required accuracy. To achieve this, it is needed to aim for promoting efficient analyses by simplified and speed-up, and for establishing an efficient analysis planning method that combines the DQO process[4] with statistical methods.

For high radiation dose waste, sampling and analysis themselves are difficult, and the amount of analysis data to be obtained is limited. Thus, statistical inventory estimation based on the radionuclide transfer model becomes important. It is necessary to efficiently obtain actual sample data with an analysis planning method that combines the DQO process with statistical methods, such as ongoing efforts for sampling from cesium sorption apparatus and its analysis, which is currently in progress. The priority of the data to be collected should also be considered to enhance the accuracy of the radionuclide transfer model.

Following the phase of analyzing samples that are easy to collect, characterization is now in the phase of collecting/analyzing samples that are important for waste management. Going forward, it is important to develop a medium-to-long-term analysis strategy that defines the solid waste to be analyzed, its priority, the objective of the analysis, quantitative targets, etc., and to proceed with analysis/evaluation accordingly. It is useful to accumulate trial results and verify their validity in order to establish a flow from the development of an analysis planning method that combines the DQO process and statistical methods; data acquisition and analysis; the incorporation of the acquired data into an examination of processing/disposal methods and evaluation of the outcome; to the development of the fiscal analysis plan based on the evaluation results.

As for facilities for analysis, in addition to the existing facilities in the JAEA’s Ibaraki area, etc., the Radioactive Material Analysis and Research Facility Building-1 was completed in June, and TEPCO also plans to install new facility for analysis, enabling characterization of a variety of solid waste in parallel. Since the target nuclides, analysis items, accuracy, and the number of samples for analysis differ depending on the target solid waste, a structure should be established based on the appropriate division of roles according to the characteristics of facilities and the objective of analysis.

3.2.2.2 Storage/management

For storage/management of solid waste should be appropriately made to the risk depending on radioactivity concentration and properties, etc. Moreover, it is important to reconsider measurement

[4] A method to plan analytical samples for decision makings developed by U.S. Environmental Protection Agency

items and timing, etc., in terms of diverse information for characterization, while acquiring necessary information through continuous monitoring and surveillance of the storage/management status commensurate with the risks involved.

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 reuse and recycle, by the end of FY 2028. To achieve this goal, it is necessary to promote volume reduction through incineration of felled trees, used protective clothing, etc., and cutting/crushing of metals and concrete, and steadily consolidate storage inside buildings.

Due to the delay in installing the ALPS slurry stabilization/treatment system, the upper limit of the cumulative absorbed dose (5000 kGy) has been exceeded before the commencement of stabilization process, and the number of HICs that need to be transferred has increased. Although there is no immediate impact on their integrity in a stationary state, it is necessary to manage HICs appropriately until they are transferred and safely complete the early installation of the stabilization/treatment system and immediate transfer.

With regard to high-activity waste, such as waste generated from fuel debris retrieval, the issues and countermeasures assuming further expansion of fuel debris retrieval in scale have been clarified according to the results of research/development as of FY 2021. Going forward, reviews should be performed along with the examination of the fuel debris retrieval methods. Measures should be taken to ensure storage/management of solid waste that is expected to be generated during fuel debris retrieval (trial retrieval, gradual expansion of the retrieval scale) before full-scale retrieval.

The site also has solid waste stored before the accident, and a large volume of dismantled waste is expected to be generated after the completion of fuel debris retrieval. Only increasing storage capacity for solid waste will eventually reach the limit, so efforts should be made to reduce the volume of solid waste to be generated as much as possible.

As volume reduction is extremely important for the safe and reasonable management of solid waste according to the progress of decommissioning work in the future, the measures in progress should be continued steadily. Since solid waste continues to be generated, it is important to continuously examine further possibilities by referring to advanced cases of overseas for more volume reduction. It is recommended that volume reduction is realized in consideration of the expected outcome and feasibility.

With an aim to reuse/recycle metals with extremely low surface dose rate, decontamination by melting (decontamination by melting slag), are under consideration as metal decontamination methods for recycling. As metal recycling with decontamination by melting slag has already been used in many Western countries, it is considered a promising candidate technology. Thus, it is important to focus on the areas where the conditions are different between Western countries and the Fukushima Daiichi NPS (target nuclides, etc.), and to evaluate the applicability of the method.

The portion of concrete debris for which the surface dose rate has been confirmed to be equivalent to the background radiation dose has already been recycled as roadbed materials.

However, given that it will be continuously generated as the decommissioning work progresses to be generated, it is necessary to appropriately evaluate the balance between the amount generated and the amount recycled in the future and consider the lead time if additional measures are required.

3.2.2.3 Processing/disposal

To specify measures for the optimization and rationalization of the overall picture covering the entire waste stream, the trial examples of optimization/rationalization of processing/disposal methods will be accumulated by waste stream to acquire findings on optimization by waste stream widely. Therefore, it is necessary to continue R&D of processing and disposal technologies required for the series of studies as shown in Fig. 16.

Regarding the processing technologies, pending issues in low and thermal processing technology, for which research/development is promoted, should be addressed. Waste streams, for which the application of normal-temperature and thermal processing technologies has not been investigated, will be evaluated as necessary, and performance of solidified waste to be produced to leach to groundwater after disposal will be evaluated. As for normal-temperature processing technology, consideration is given to transformation of solidified waste as well as inspection methods to verify the possibility of solidification. In the case of thermal processing technology, the feasibility of the whole processing system, including supply and exhaust systems, is an issue in addition to the solidification process, and therefore it is necessary to carry out examination in a timely manner according to the start time of processing.

Concerning disposal technology, to enhance the reliability of the disposal concept, it is necessary to evaluate its feasibility based on a study of the long-term evolution behavior of the disposal facilities in light of the characteristics of waste form and to incorporate the results into the discussion of the disposal concept. To appropriately allocate waste to a disposal concept that is shown to be feasible, knowledge on the sensitivity structure of the scenarios and parameters to radiation should be expanded by adequately incorporating those characteristics of waste, changes in environmental conditions in and around disposal facilities into the scenarios and parameters of radiation dose assessment, and repeating tests. Using this knowledge to propose safe and reasonable disposal options is important. Furthermore, after expanding the target of waste streams incorporating this disposal option, a group of disposal options will be examined with a bird-eye-view of all solid waste at the Fukushima Daiichi NPS. Then, contributions will be made to considering specific management approaches for solid waste in coordination with areas other than disposal, such as presenting targets for waste form performance and the accuracy required for characterization.

In examining these, it is important to flexibly consider the most appropriate measures, taking into account the actual use and economic feasibility by reflecting the newest findings and applying the concept of the Best Available Techniques. As the examination progresses, and the processing/disposal methods for the overall picture of waste are finalized, it will be important to share the examination process for optimization, such as by sharing the awareness of problems with local communities and society.

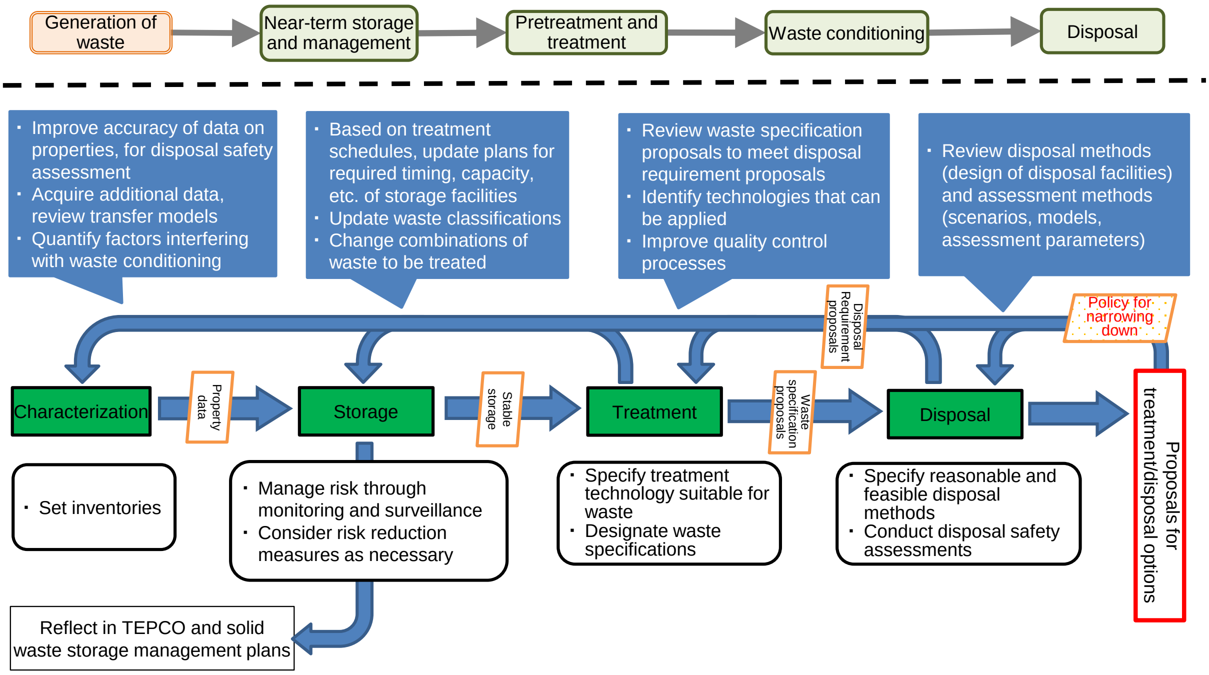


Fig. 16 Procedure to reasonably select safe processing/disposal methods of solid waste

The main technical issues and plans in the future described in this section are summarized as shown in Fig. 17.

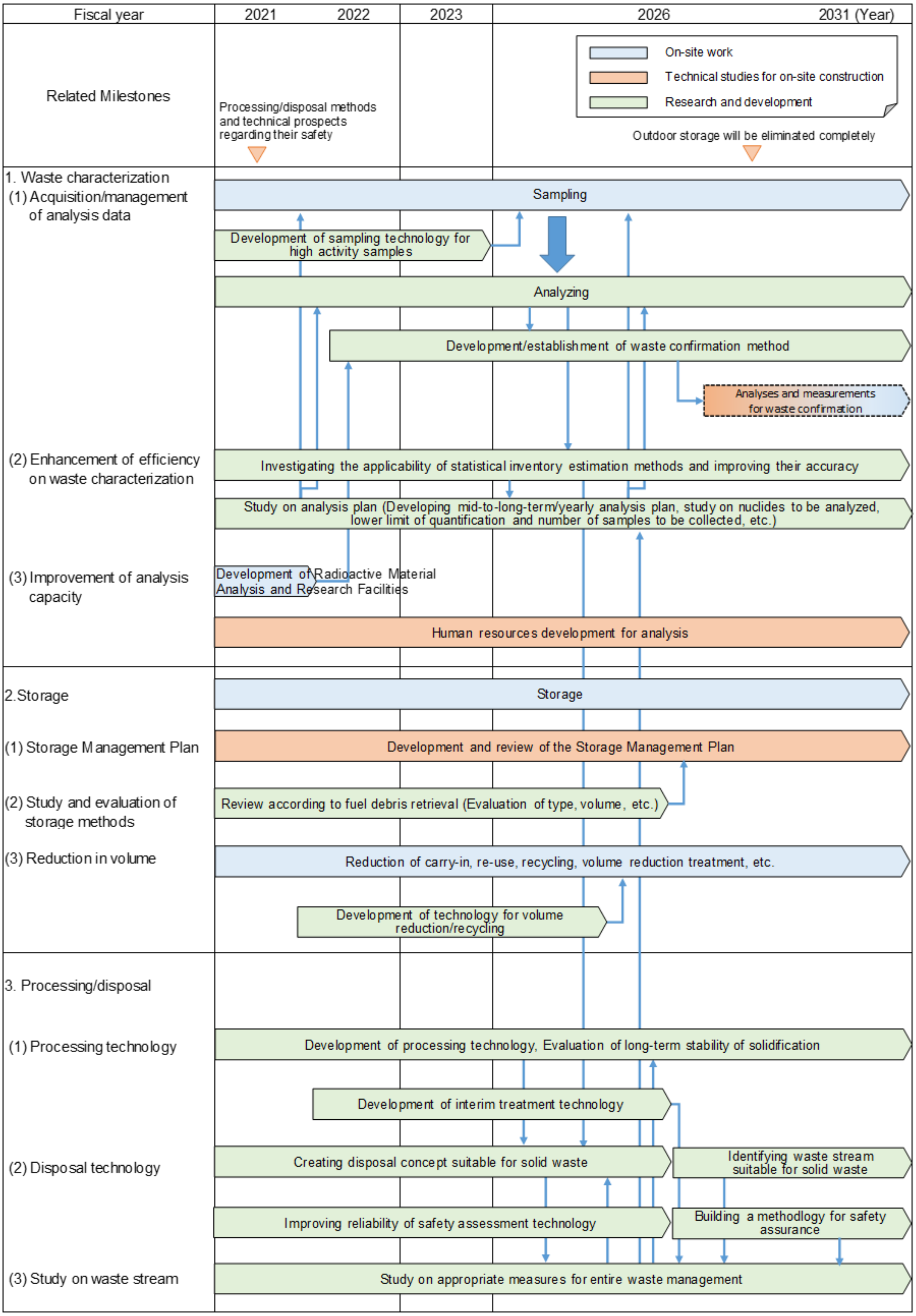


Fig. 17 Main technical issues and future plans on waste management (progress schedule)

3.3 Contaminated and treated water management

3.3.1 Targets and progress

(Targets)

(1) Under the three principles concerning the contaminated water issues ("Removing" contamination sources, "Redirecting" fresh water from contamination sources, and "Retaining" contaminated water from leakage), to reduce the stagnant water in the reactor buildings in FY 2022 to FY 2024 to about the half of the amount of the end of 2020 while continuing the operation of the constructed water-level management system and controlling the generation amount of the contaminated water to 100 m^3/day or less in 2025. Moreover, to ensure stable implementation of contaminated water management, measures against large-scale natural disaster risks, such as tsunamis and storm rainfall, will be implemented in a planned manner.

(2) To arrange the relationship with a decommissioning process including full-scale fuel debris retrieval beginning in the near future, and to promote examination of the measures of the contaminated water management for medium-and-long term prospects.

(3) For ALPS treated water currently stored in tanks, measures will be taken for discharging approximately two years after the “Basic Policy on Disposal of ALPS-Treated Water” (released in April 2021).

(Progress)

Stagnant water in buildings, that is, the contaminated water with a mixture of cooling water contacted with the fuel debris and groundwater/rainwater flowed into the buildings is liquid containing a considerable amount of the dissolved radioactive materials (inventory) from the perspective of measures to reduce the risk from radioactive materials. Therefore, its hazard potential is high and so is the Safety Management level, as the storage condition of such stagnant water deviates from what is originally intended. For this stagnant water in buildings, excluding the reactor buildings of Units 1 to 3, where circulating water injection is ongoing, the process main building and high-temperature incinerator building storing contaminated water temporarily for purification treatment, the treatment of stagnant water in buildings was completed in 2020, and the inventory was significantly reduced. However, the hazard potential is still high.

Currently, the following four measures are being implemented as contaminated water management:

(1) Efforts to promote contaminated water management in accordance with the three principles ("Removing" contaminant sources, "Redirecting" fresh water from containment sources, and "Retaining" contaminated water from leakage")

The groundwater level in the vicinity of the reactor buildings was stably controlled at low levels through multilayered contaminated water management such as land-side impermeable walls and sub-drains. The increase in the amount of contaminated water generated during rainfall also tended to be controlled by repair of damaged roofs and facings on site. As a result, the amount of contaminated water generated decreased from approx. 490 m^3/day (FY 2015) before the measures were taken to approx. 130 m^3/day (2021). In order to reduce the amount of contaminated water to 100m^3/day or less by the end of 2025, roof repair and expansion of facing range are being addressed while adjusting interference with other decommissioning work.

(2) Efforts to complete stagnant water treatment

In 2020, the treatment of stagnant water in buildings, excluding the reactor buildings of Units 1 to 3, the process building and high-temperature incinerator building, was completed. With the aim of reducing the amount of stagnant water in reactor buildings to approximately half of that at the end of 2020 between FY 2022 and FY 2024, the water level in the Unit 2 reactor building was carefully lowered while parameters such as PCV pressure and dust concentration were monitored, and the target level of T.P.-2,800 was first reached in March 2022.

It is planned to lower the water level in the reactor building while continuously lowering the sub-drain water level in order to reduce the amount of stagnant water in the reactor building by half. In association with this, the importance of issues in handling sludge containing α-nuclides (hereinafter referred to as the "α-sludge") at the bottom of the reactor building is increasing. As the particle size distribution and chemical composition of the α-sludge have been analyzed, it is expected that most of the sludge can be removed by a filter with an appropriate pore diameter. In order to complete the treatment of stagnant water in the process building and the high-temperature incinerator building, moreover, methods for radiation dose rate surveillance or recovery are under consideration for high-dose zeolite sandbags located on the lowest floor. In the case of a building where the treatment of stagnant water has been completed and the floor surface has been exposed, a method for recovering sludge located on the floor is being studied.

(3) Efforts for stable operation of contaminated water management

As for tsunami countermeasures, construction of the Kuril Trench tsunami tide walls were completed in September 2020, and the measures for closing building openings were taken in January 2022, followed by the installation of the Japan Trench tsunami tide walls, , reinforcement of the land-side impermeable walls, relocation of sub-drain and other water collection systems from the revetment side to higher ground, and transfer of sludge generated by decontamination devices to higher ground. As a countermeasure for heavy rain, installation of drainage channel D to eliminate the risk of inundation in the vicinity of Units 1 to 4 and reinforcement of discharge functions of the existing drainage channel, etc., are underway.

While the importance of multilayered measures including land-side impermeable wall has not changed, in light of the damage to equipment, such as brine leakage, it is important to strengthen monitoring, procure and arrange spare parts and substitutes, and establish a framework for taking restoration measures as soon as possible in the future. Furthermore, the earthquakes that occurred on February 13, 2021, and March 16, 2022, did not cause leakage in tanks for storing the treated water, but caused sliding of the tanks (53 units and 160 units, respectively). Moreover, displacements exceeding the manufacturer's recommended limits[5] have been confirmed in some of the connecting pipes, however, since the connecting valves are fully closed, the stored water in the tanks will not leak, even if it should break.

(4) Efforts toward discharging ALPS-treated water into the ocean

On April 13, 2021, under the overriding principle of Balancing between Reconstruction and Decommissioning, and on the premise of ensuring safety and implementing comprehensive measures to prevent reputational damage, the Government announced the basic policy for discharging ALPS-treated water into the ocean from the Fukushima Daiichi NPS after comprehensive discussions at expert meetings for more than six years. In addition, the Government requested TEPCO to proceed with preparations, including the installation of a specific discharge system, aiming to start the discharge of ALPS-treated water into the ocean in about two years.

In response to this policy, on April 16, 2021, TEPCO indicated their approach to ensuring safety through further efforts and in compliance with regulatory standards pursuant to laws and regulations; minimizing reputational damage; providing compensation in the event of reputational damage; and addressing issues for the future. TEPCO has also started working to provide a briefing for stakeholders, and to obtain permission for the implementation plan.

As part of its initiatives since the announcement of the basic policy, the government compiled and disclosed immediate measures at the second meeting of the Cabinet Meeting for the Steady Implementation of the Basic Policy on Disposal of ALPS-treated Water and a specific action plan at the third meeting. The task force on monitoring and measuring the marine environment and the Expert Meeting for Marine Monitoring related to ALPS-treated water were established in June 2021 to enhance marine monitoring. In July 2021, the government signed the Terms of Reference with the International Atomic Energy Agency (hereinafter referred to as “IAEA”) and requested support for the discharge of ALPS-treated water.

Meanwhile, TEPCO announced in August 2021 the status of the facilities study for ensuring safety and published the results of its assessment that the impact of the discharge of ALPS treated-water into the ocean on human and the environment would be extremely small in the Radiological Impact Assessment Regarding the Discharge of ALPS Treated Water into the Sea (Design stage) in November 2021 to solicit comments. In December 2021, TEPCO submitted Application Documents for Approval to Amend the Implementation Plan for a Specified Nuclear Facility for ALPS Treated Water Dilution/Discharge Facilities and Related Facilities to the Nuclear Regulation Authority for review on the operation method of offshore discharge facilities and safety during discharge into the ocean, and gained approval in July 2022.

In addition, the IAEA conducted a safety review on the handling of ALPS-treated water in February 2022 and a review of the regulations of ALPS-treated water in March 2022 based on the

[5] It is a reference value that allows the pipe to be used safely even if displacement occurs. The design value has a margin of about 2 to 4 times to this value.

Terms of Reference with the government. The IAEA published review results reports in April 2022 and June 2022, respectively.

The discharge of waste liquid generated in nuclear facilities into the ocean, pursuant to the law with a sufficiently small radiological impact on the human population and the natural environment is a method recognized globally and widely adopted in Japan and abroad. On the other hand, it is also a fact that there have been concerns about reputational damage due to the discharge of ALPS-treated water into the ocean. Therefore, efforts should be continued to deepen understanding to eliminate such concerns. Therefore, greater transparency is required, for example, by repeatedly providing explanations in an easy-to-understand and careful manner, mainly by TEPCO, in order to increase understanding of (1) an operation plan for offshore discharge; (2) the effects of radioactive material such as tritium contained in the water to be discharged to the ocean on the human body; and (3) the method for verifying the operation status as the basics for implementing safe discharge, and by verifying these through reliable third parties such as IAEA in cooperation with organizations concerned, and by delivering accurate information.

TEPCO's planned discharging system, if operated reliably, will have no adverse effects on humans and the environment, and therefore it is an important issue to operate the system "reliably" “as planned”. The following is a summary of the progress made by TEPCO on each of the items listed in Technical Strategic Plan 2021.

- In the operational phase, develop a series of operation plans including system operation, analysis of ALPS-treated water, flow control of the treated/diluted water, marine monitoring, maintenance, and troubleshooting, and then develop a system plan that minimizes risks and eliminates social concerns
  => TEPCO's system and operation plans will be approved by the Nuclear Regulation Authority in July. However, the nuclides to be measured/assessed before discharge into the ocean will be selected after verifying the nuclides that can be significantly present in ALPS-treated water. NDF provides technical advice and support on the selection method of nuclides to be analyzed and the evaluation method of nuclide concentration.
- Perform a radiological impact assessment on the human population and the natural environment, and disclose evaluation results based on the specific discharge plan
  => In April 2022, TEPCO submitted to the NRA the statement of the radiological impact assessment revised based on the review by IAEA and the international experts as well as discussion with the NRA. Based on the selection results of the nuclides to be assessed, the radiation environmental impact will be verified.
- Verify safety by experts from the IIAEA and other agencies
  => In February 2022, the IAEA conducted a safety review on the handling of ALPS-treated water and announced that preventive measures were adequately taken in the design of

the discharge system in light of international safety standards and that the radiological impact on humans is significantly smaller than the reference values proposed by international organizations and the level specified by regulatory authorities. The next review mission is scheduled for late 2022, and a comprehensive report with final conclusions and findings will be published before the discharge of ALPS-treated water begins.

- Develop a plan to strengthen marine monitoring, and perform marine monitoring before the discharge
  => The Government's Monitoring Coordination Council, held on March 30, 2022, provided a plan for strengthening and expanding marine monitoring by the government (MOE, NRA, etc.), TEPCO, and Fukushima Prefecture. The monitoring started in April 2022. TEPCO is proactively conducting monitoring in cooperation with the government and local governments, etc.

- Education and training on analysis for parties concerned including contractors
  => TEPCO explained education and training plans on analysis to the NRA in the open screening panel. A review was performed on competence management methods related to analysis, and education and training.

- Development of strategies to provide accurate and understandable information domestically and internationally without causing anxiety from a social perspective, and timely dissemination of the status of preparations
  => TEPCO has continuously held 1F tours and round-table talks for residents living in 13 municipalities along Hamadori and other areas in Fukushima Prefecture, and disseminated information on decommissioning and ALPS-treated water through the local newspaper advertisement. In addition, TEPCO has accepted site visits by foreign government officials, etc., as well as provided the latest information on the discharge of ALPS-treated water into the ocean not only in Japanese, but available in English, Chinese, and Korean on TEPCO's "Treated Water Portal Site".

- Ensuring implementation of measures against reputational damage as set forth in the Government's basic policy announced in April 2021
  => The Government announced an action plan at "the third meeting of the Cabinet Meeting for the Steady Implementation of the Basic Policy on Disposal of ALPS-treated Water" (revised in August 2022) held in December 2021. Based on the action plan, TEPCO is making efforts to minimize reputational damage through reviews by the NRA and the IAEA, and safety checks by local governments based on agreements to ensure the safety of decommissioning. NDF promotes understanding and disseminating accurate information according to the interests of the recipients through meetings with relevant organizations in foreign countries and international conferences

3.3.2 Key issues and technical strategies to realize them

3.3.2.1 Issues in the future treatment of stagnant water in buildings

The following three points are the key issues for the future treatment of stagnant water in buildings.

(1) Prevention of spreading α-nuclides

At the bottom of the torus room of the reactor building, stagnant water in which α-nuclides from fuel debris exist in the form of fine particles (α-sludge) and ions, and a relatively high concentration of total α-nuclides has been detected. Since the effective dose factors of α-nuclides is remarkably high when inhaled or ingested, special management and countermeasures are required if α-nuclides spread to stagnant water in buildings or water treatment systems. The spread of α-nuclides should be as limited as possible to avoid such a situation.

The investigation in FY 2021 revealed the following two points on the spread of α-nuclides.

- The highest total α concentration to date was detected in accumulated water collected in the Main Steam Isolation Valve room of Unit 3.
- A relatively high total α concentration was detected in the bottom sludge of the D1 and D2 tanks in the Area E.

The total α concentration of the accumulated water collected in the Main Steam Isolation Valve chamber of Unit 3 was about three times (1.7×10^6 Bq/L) that of the stagnant water collected from the bottom of the reactor building of Unit 3, which had the highest concentration. It is presumed that this accumulated water is part of the water inside the PCV flowing directly into the Main Steam Isolation Valve chamber from the damaged expansion joint of the main steam pipe connected to the PCV. Moreover, it was found that the total α concentration of the collected accumulated water would decrease to about 1/1000 by filtration, indicating that most of the α-nuclides exist as fine particles.

Tanks D1 and D2 in Area E store water collected from residual water at the bottom of the tanks generated by dismantling flanged tanks that stored RO-enriched saltwater. As a result of measuring the total α concentration of the water mixed with sludge at the bottom of the tanks, the total α concentration (5.3×10^3 Bq/L) of the same level as the stagnant water in buildings was detected. This bottom sludge is to be recovered from the top manway of the tank by feeding an underwater pump.

As described above, the situation of α contamination in the Unit 3 reactor building and the presence of α sludge due to the treatment of residual water at the tank bottom are becoming apparent. In particular, attention should be paid to the fact that α contamination spreads mainly through fine particles (sludge components). At present, a total α concentration in the order of 10 Bq/L is maintained at the cesium sorption apparatus (SARRY/SARRYII) inlet, and the spread of contamination to the downstream side is suppressed. However, as the stagnant water level of the reactor building is lowered further in the future, more sludge at the bottom of the building may be mixed, and the total α concentration at the water treatment system inlet may rise. TEPCO is considering installing filter systems in the subsequent stage of the cesium sorption apparatus in response to such concerns.

(2) Further lowering of groundwater levels to reduce the amount of contaminated water generated

Since there is highly concentrated stagnant water at the bottom of the torus room of the reactor building, a sudden change in concentration during treatment of the stagnant water will interfere with the treatment system in the subsequent stage. Therefore, the water level of stagnant water in buildings will be carefully lowered to approximately 10 cm in 2 weeks for each building.

Although the water level is controlled in the floor sump in the buildings with exposed floor surfaces, there is a possibility that the sump may overflow temporarily during heavy rains such as typhoons. The overflowing water must be treated as stagnant water in the building, which is highly contaminated by fuel debris, and the water level difference with the sub-drain must be secured (800 mm or more). Therefore, in preparation for the risk of deviation from the limiting conditions for operation (LCO) during heavy rain, the sub-drain water level is maintained higher in advance, causing an increase in the inleak into buildings. Since the floor of these buildings is higher than the level of stagnant water in the reactor building, water that inleaks into the floor sumps during heavy rainfall is derived from rainwater and groundwater. As the risk of leakage of stagnant water in the reactor building does not increase even if the water level rises, it is necessary to review the water level management method for the buildings where exposed floor surface has been achieved in the future.

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

As the basement floors of the process main building and the high-temperature incinerator building are storing stagnant water, TEPCO aims to lower the water level to expose the floor surface of the buildings from FY 2024. To realize this, it is essential to take measures against high-dose zeolite sandbags placed on the basement floors of the process main building and the high-temperature incinerator building and install temporary storage tanks for stagnant water in place of storage in the basement floors.

In the basement floors of both the process main building and the high-temperature incinerator building, zeolite sandbags placed shortly after the accident are found to exist in a high-dose state, and the maximum surface dose from the sandbags is extremely high at approximately 4,400 mSv/h, and activated carbon sandbags also exist. When these basement floors are exposed, it is expected that the radiation dose will increase significantly at the openings of the above-ground floors due to the loss of water shielding.

The procedure for recovering zeolite sandbags under consideration is to first collect as many zeolite sandbags as possible in a submerged environment to increase work efficiency, then transfer the collected zeolite and other materials to the ground level using a recovery robot (ROV + pump), desalinate and dehydrate them in the building, seal them in metal storage containers, and transfer them to temporary storage facilities. The first step of collecting will be carried out in FY 2023, and the second step of containing will be from FY 2023 to FY 2024. In this task, zeolite will be collected and recovered by suction in the form of particles, which may apply to the recovery of high-dose sludge deposited on the floor surface of the reactor building to be planned, providing critical knowledge for the future progress of decommissioning work.

However, the basement floors of the process main building and the high-temperature incinerator building have been used as storage tanks for tens of thousands of cubic meters worth of stagnant water in buildings, where water with different chemical properties and radioactivity transferred from the Unit 1 to 4 buildings has been mixed, averaged, and treated by the cesium sorption apparatus. For this reason, studies are underway on temporary storage tanks for stagnant water that will take over the following functions that the process main building and the high-temperature incinerator building have performed.

- Receiving stagnant water in buildings
- Stagnant water buffer for stable operation of cesium sorption apparatus (KURION, SARRY, and SARRYII)
- Concentration averaging of stagnant water in each building
- Settlement of sludge

These temporary storage tanks for stagnant water will be installed on the fourth floor of the process main building. The basement floor of the process main building after tank installation will be used only when the inflow volume increases during heavy rain. To take over the functions described above, temporary storage tanks for stagnant water will consist of two types of tanks: a temporary receiving tank for receiving water and settling sludge and a temporary storage tank for homogenizing the water concentration. The capacity of the temporary receiving tank is assumed to be approximately 10 - 20 m^3, and that of the temporary storage tank is approximately 20 m^3. The capacity is considerably smaller than that of the basement floors of the the process main building (maximum capacity: approximately 16,000 m^3) and the high-temperature incinerator building (maximum capacity: approximately 5,000 m^3). In the future, an examination from operational aspects is needed to maintain the functions even with a small capacity. The installation work of the temporary storage tanks for stagnant water is scheduled from FY 2023 to FY 2024, and these tanks will be operated from FY 2024.

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

The following two points are the key issues of contaminated water management considering the decommissioning process such as fuel debris retrieval.

(1) Examination of water treatment systems for fuel debris retrieval

In examining water treatment systems for fuel debris retrieval, it is essential to review the overall picture of how to share the functions with the existing treatment systems for stagnant water in buildings (SARRY, ALPS, etc.) and establish an appropriate configuration. At the same time, planned replacement of the existing water treatment systems is also required. To carry out such an examination, determination of the required specifications and basic design for the water treatment systems for fuel debris retrieval must be implemented promptly.

When retrieving fuel debris, contaminated water containing a large amount of fine particles is generated by fabrication including cutting and other processes, and α-nuclides in fuel debris may exist in various forms such as fine particles, ions, and colloids. Because the water quality of such contaminated water depends on fabrication method including cutting and other processes, it is difficult to assume the water quality in a situation where the fuel debris retrieval method has not been determined. An issue arises that the water treatment systems for fuel debris retrieval should have a complicated system configuration to cope with a wide range of water quality and different forms of α-nuclides.

However, analysis of the stagnant water in buildings has shown that the concentration of total α can be reduced to 1/100 to 1/1,000 by filtration, indicating that most α-nuclides can be removed by simple filtration. Since simple fabrication including cutting and other processes without the use of chemicals lead to only small changes in chemical water quality, most α-nuclides are generated as fine particles, as in these analyses, and the concentration of soluble α-nuclides may be maintained at a low level. Therefore, it is important to verify the form and particle size of α-nuclides at the sampling points and incorporate them into the system design for further expansion of fuel debris retrieval in scale.

To establish fabrication methods including cutting and other processes, laboratory tests should be conducted to determine their impact on the chemical changes in water quality, which will enable the establishment of realistic water quality conditions for contaminated water and lead to rationalization and improved reliability of the water treatment systems.

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

It is necessary to ensure that periodical inspection and updating of equipment, including land-side impermeable walls, sub-drain systems and existing water treatment systems (e.g. SARRY, ALPS), is implemented in order to maintain the effectiveness of contaminated water management over the medium-to-long term. For this purpose, it is important to anticipate various risks, such as deterioration of system functions caused by aging, metallic fatigue due to traffic loads, damage of piping caused by natural disasters; to procure/arrange backup and alternative items for the enhanced structure for monitoring and early recovery, and for stable operation; and to promote maintenance/management and system updates in a planned manner.

While the current contaminated water management is shifting to a certain stable state, in addition, it takes a long time to complete fuel debris retrieval. Along with the selection of methods for further expanding the scale of fuel debris retrieval currently in progress, it is important to see a medium-and-long term, overlook the current contaminated water management anew, and examine the principles of more stable contaminated water management and more appropriate maintenance/management of each system. Furthermore, the interference with fuel debris retrieval work needs to be considered as contaminated water management in anticipation of the decommissioning process.

As exemplified in 3.1, partial submersion method and submersion method are currently under examination for fuel debris retrieval. In addition to verification of actual site applicability and technical feasibility, both methods need consideration of measures to prevent contaminated water from leaking out from inside the building and control groundwater inleak into the building from the outside. In the future, it will be necessary to consider medium and long-term contaminated water management and fuel debris retrieval methods.

3.3.2.3 Issues for discharging ALPS-treated water into the ocean

In July 2022, TEPCO gained approval from the NRA on facilities for offshore discharge of ALPS-treated water, their operation methods, and safety during discharge into the ocean. TEPCO also underwent a review on safety in handling ALPS-treated water by the IAEA, indicating that preventive measures were adequately taken in the design of the discharge facilities in light of international safety standards and that the radiological impact on humans is significantly smaller than the level specified by regulatory authorities.

Going forward, it is an important issue for TEPCO to operate the established plan "reliably", and it is necessary to ensure the implementation of each plan (system, operation, information distribution, etc.), to perform check and review, and to review and expand the plan as needed, as well as to ensure its transparency. It is necessary to build systems based on the approved implementation plan and ensure that education, training, and other preparations for its operation are provided.

- Ensuring establishment of planned facilities and their reliable operation (including system operation, analysis of ALPS-treated water, flow control of the treated/diluted water, marine monitoring, maintenance, and troubleshooting)
- Reassessment of radiation impacts on human and environment based on the selection results of nuclides to be analyzed and publication of the assessment results
- Perform marine monitoring before, during and after the discharge in accordance with the developed marine monitoring plan
- Continued implementation of the following
  - Verify safety by experts from IAEA and other agencies Education and training on system operation and analysis, etc., for parties concerned including contractors
  - Development of strategies to provide accurate and understandable information domestically and internationally without causing anxiety from a social perspective, and timely dissemination of the status of preparations
  - Ensuring implementation of measures to prevent reputational damage as set forth in the Government's basic policy announced in April 2021

In order to prepare for ensuring prompt and reliable site usage after the discharge of treated water, TEPCO also needs to develop a plan to discharge in accordance with the site use plan and appropriately revise the plan according to the situation, in considering concentration of tritium contained in treated water in tanks and attenuation.

NDF will provide technical and professional support for TEPCO's construction of facilities and preparations for the start of operations, while promoting distribution of accurate information and increasing understanding through meetings with relevant organizations in other countries and international conferences in line with the interests of those who will receive the information. NDF will also ensure that TEPCO implements measures to minimize reputational damage, and that TEPCO takes action with adequate and sufficient compensation in the event of reputational damage.

3.3.2.4 Summary of major technical issues

The main technical issues and plans described in this section are summarized as shown in Fig. 18, and Fig.14 shows the future plans for the water treatment system for fuel debris retrieval.

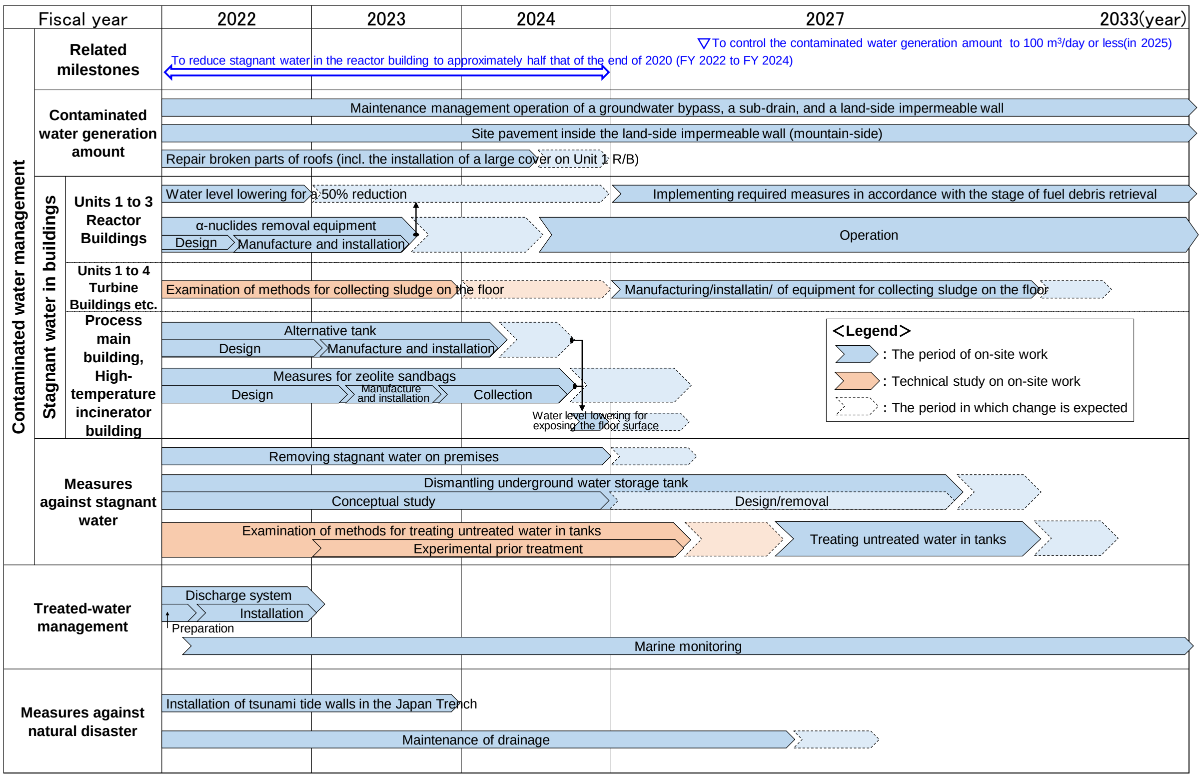


Fig. 18 Key technical issues and future plans on contaminated water and treated water management and natural disaster preparedness (progress schedule)

3.4 Fuel removal from spent fuel pools

3.4.1 Targets and progress

(Target)

(1) The aim is to complete fuel removal from all spent fuel pools of Units 1 to 6 in Phase 3-[1] of the Mid-and-Long-term Roadmap.

(2) While the return of residents and reconstruction in the surrounding area is gradually advanced, to carry out a risk assessment and ensure safety including preventing 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.

(3) The fuel in Units 1 to 4 that were affected by the accident are retrieved from the SFPs and transferred to the Common Spent Fuel Storage Pool, etc., where they are appropriately stored so that they are 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 Dry Cask Temporary Custody Facility.

(4) To perform the evaluation of long-term integrity and the examination for treatment for the retrieved fuel and to decide the future treatment and storage method.

(Progress)

In Unit 1, from the perspective of further reduction of radioactive dust dispersion risk, a method in which the whole operating floor was covered with a large cover to remove rubble and fuel from SFP inside the cover, was adopted. In preparation for the installation of large covers and subsequent rubble removal operations, measures to prevent and mitigate the dropping of rubble, such as installing supports for overhead cranes and fuel handling machines, and curing the SFP in order not to affect fuel in SFP, were completed in November 2020. The removal of the existing interfering building cover (remaining portion) was completed in June 2021. Subsequently, the area around the reactor building has been improved. Still, delays in removing SGTS piping (removal of high-dose pipes by remote control) caused delays in the preparatory work. In light of the review status of the application of the new seismic design policy presented by the NRA, TEPCO states in its Mid-and-Long-term Decommissioning Action Plan 2022 that it will reconsider the installation process of the large cover for Unit 1 due to the construction work interference (caused by the delay in preparatory work). The installation period in the progress schedule is set until around the end of FY2024, with the goal of completing the installation by FY2023. Fuel removal in Unit 1, a milestone in the Mid-and-Long-term Roadmap is expected to begin in FY 2027 - FY 2028 as planned. TEPCO plans to obtain approval of the implementation plan for installing the large cover and to commence the installation work of the main unit.

For Unit 2, a method in which the upper part of the operating floor will not be dismantled and with access from the working platform for fuel removal to be installed on the south side of the reactor building was adopted from the perspective of further reduction of radioactive dust dispersion risk similar to Unit 1. For constructing the working platform, installation of the base mat of working platform for fuel removal started in May. Based on the results of dose surveillance on well-plug of the operating floor and conducted in 2021, decontamination and installation of shielding on the upper part of the well were carried out. The effectiveness of radiation dose reduction was rechecked in May 2022. Preparations are underway for fuel removal, including the transfer of the existing fuel handling machine and further decontamination/shielding.

The policy is that fuel removal from Units 5 and 6 is planned so as not to interfere with operations in Units 1 and 2. In Unit 6, fuel transfer from the SFP to the common spent fuel storage pool began in August 2022.

Securing the available capacity of the Common Spent Fuel Storage Pool and transfer of some fuel in the Common Spent Fuel Storage Pool to Dry Cask Temporary Custody Facility are required to remove all the fuel in SFPs, including Units 5 and 6, and store them in the Common Spent Fuel Storage Pool. For this purpose, TEPCO is working on expanding storage capacity of Dry Cask Temporary Custody Facility and systematic off-site transportation of new fuel.

Such efforts will be made to complete fuel removal in all units in 2031.

3.4.2 Key issues and technical strategies to realize them

For Units 1 and 2, it is necessary to advance the work steadily to realize the determined new removal method.

3.4.2.1 Fuel removal from SFPs

In promoting the project, it is important to make assessment of safety in association with work and confirming that necessary and sufficient safety is ensured. Moreover, it is essential to comprehensively consider technical reliability, rationality, promptness in the work schedule, actual site applicability and project risk, etc.

For Unit 1, the installation of the large cover, and the removal of leftover objects such as rubble on the operating floor will be promoted. Although overhead crane support is installed on the upper part of the operating floor for fall prevention, it is still in an unstable state. Therefore, removing the overhead crane in a safe and reliable way is one of the main issues to prevent it from collapsing onto the fuel handling machine and falling into SFP. Although TEPCO has drafted the removal method of the overhead crane, the information on the condition of the lower part of the roof slab is limited at present, requiring reverification by a detailed investigation after the removal of the slab. There is a risk of delay in the crane dismantling process depending on the reverification result. Therefore, it is important to plan work procedures after identifying required tasks such as surveys and verification, promptly investigate overhead cranes, etc., as soon as investigation becomes possible, and incorporate them into safety assessments and rubble retrieval plans, including risk cases.

Although the well-plugs of Unit 1 have been evaluated by the Study Committee on Accident Analysis of the Fukushima Daiichi NPS to be about two orders of magnitude less contaminated than several tens of PBq of Units 2 and 3, those in Unit 1 become deformed and unstable due to the impact of the explosion at the accident. For this reason, TEPCO is studying the impact of a fall on the PCV during an earthquake. Based on the study results, it is necessary to make a comprehensive decision on how to handle these well-plugs, and by taking into consideration the impact on the removal of fuel from SFP and fuel debris retrieval in the later stage, and by performing thorough safety assessments.

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

In Unit 2, fuel in SFP will be removed from the opening on the south side of the operating floor using a fuel handling machine composed of a boom-type crane-system, which has not yet been used for nuclear facilities in Japan. Since it is a new system, it is important to do the following: ① to set up an appropriate design/manufacturing schedule with margins, ② to perform mockup tests fully simulating on-site situations and operation methods and ensure feedback on the results to design and production, and ③ to be sufficiently familiar with the operation and functionality of systems beforehand in preparation for removal by remote operation.

To install a fuel handling system, it is necessary to steadily carry out preparatory work, including installing an anterior chamber on the working platform and an opening on the south side of the operating floor of the reactor building. Fuel removal from the SFP basically assumes unattended operation by remote control. However, staffed operation is also assumed during installation of some system and troubleshooting. Therefore, TEPCO plans to carry out decontamination and install shields in FY 2023 after completing the transfer of the existing fuel handling machine, etc. Under the current plan, there is a risk that the work area after decontamination will be contaminated again, and the process will be delayed due to establishing the opening on the south side of the operating floor after decontamination. Therefore, it is important to take thorough measures to prevent dust dispersion when establishing an opening.

3.4.2.2 Decision of future treatment and storage methods

The future treatment and storage methods for the fuel in SFPs need to be decided after considering the impact of seawater and rubble exerted during the accident. The impact of seawater and rubble has been evaluated for the fuel removed from Unit 4, and it is expected that the impact is small. However, based on the situation of the fuel to be retrieved, it is necessary to advance the evaluation of long-term integrity and the examination for treatment and to decide the future treatment and storage methods.

The main technical issues and plans described in this section are summarized as shown in Fig. 19.

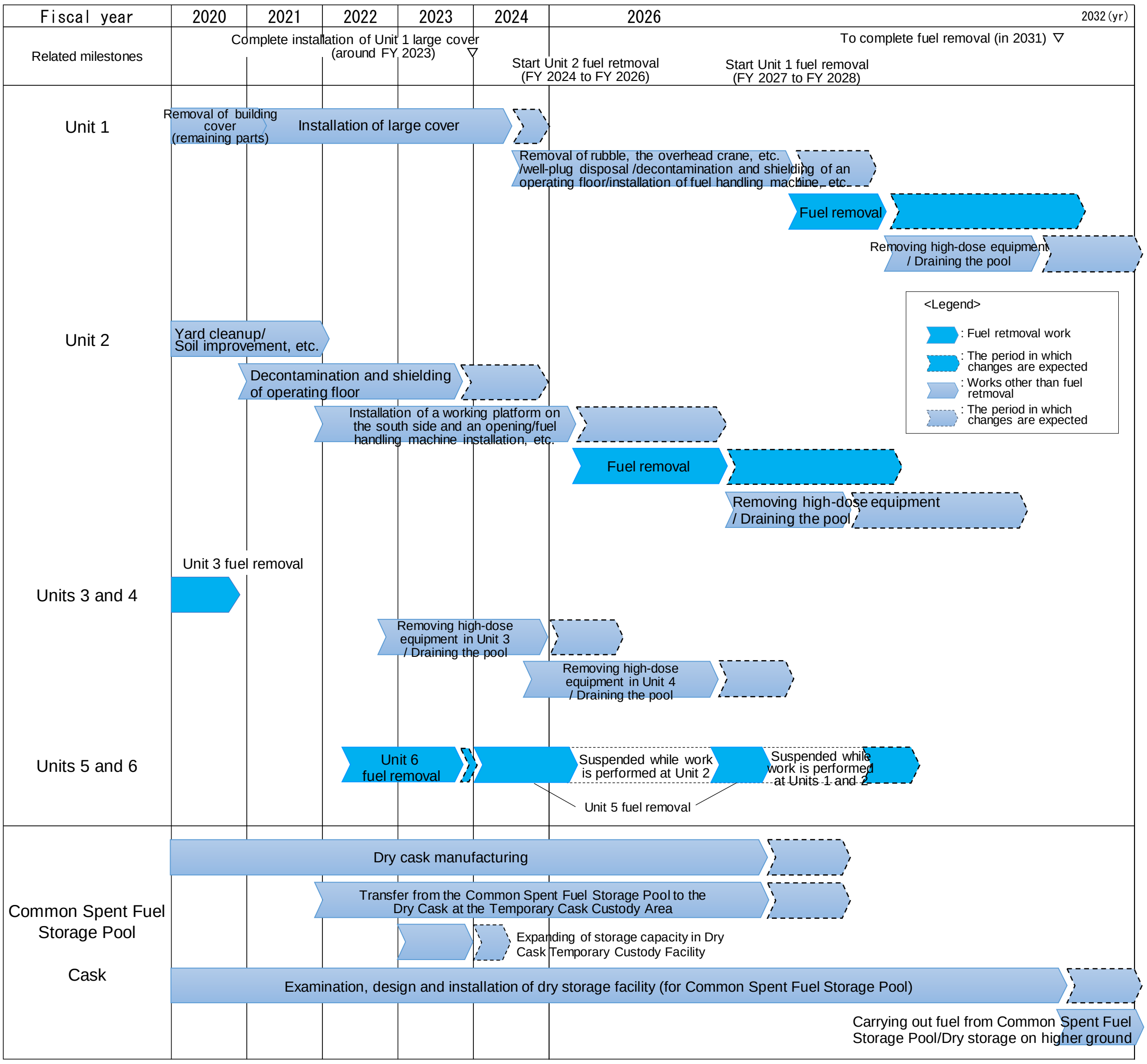


Fig. 19 Key technical issues and future plans for fuel removal from SFPs (Progress schedule)

4. Analysis strategy for promoting decommissioning

4.1 Uncertainty of fuel debris, etc. and importance of analytical results

The accident at the Fukushima Daiichi NPS was the first core meltdown accident at BWRs in the world, and there are no records of temperature and other plant parameters due to loss of power at the accident. In addition, many uncertainties remain regarding the state inside the reactors, the state of the fuel debris, and FP release paths, etc., due to the unclear operational status of the safety equipment and the injection of seawater to bring the accident under control. If the range of uncertainty is reduced, there will be no need to include excessive safety margins in safety assessments and safety measures for handling and storing of fuel debris, and thus, the promptness and rationality of decommissioning will be improved. In addition to conventional sample analyses, studies on reducing uncertainty of fuel debris properties by other measurement methods have already started since FY2020 by The Project of Decommissioning, Contaminated Water and Treated Water Management.

The analysis results of solid waste are important basic information for the study on processing/disposal methods for various kinds of waste generated by the accident. The analysis results of fuel debris are applied in a number of areas, including retrieval methods, storage management, necessity of treatment, investigation to determine the cause of the accident, and improvement of nuclear safety. Their relationship changes with the progress made in decommissioning of the Fukushima Daiichi NPS. It is important to correctly recognize that the analytical results are "one of the important criterion for decisions" for reducing the range of uncertainty in the above examination for facilitating decommissioning. TEPCO, incorporating analysis results in each decommissioning process, should take the lead in establishing and developing analysis systems, facilities, and functions that can efficiently collect and evaluate analysis results.

4.2 Three elements of analysis strategy

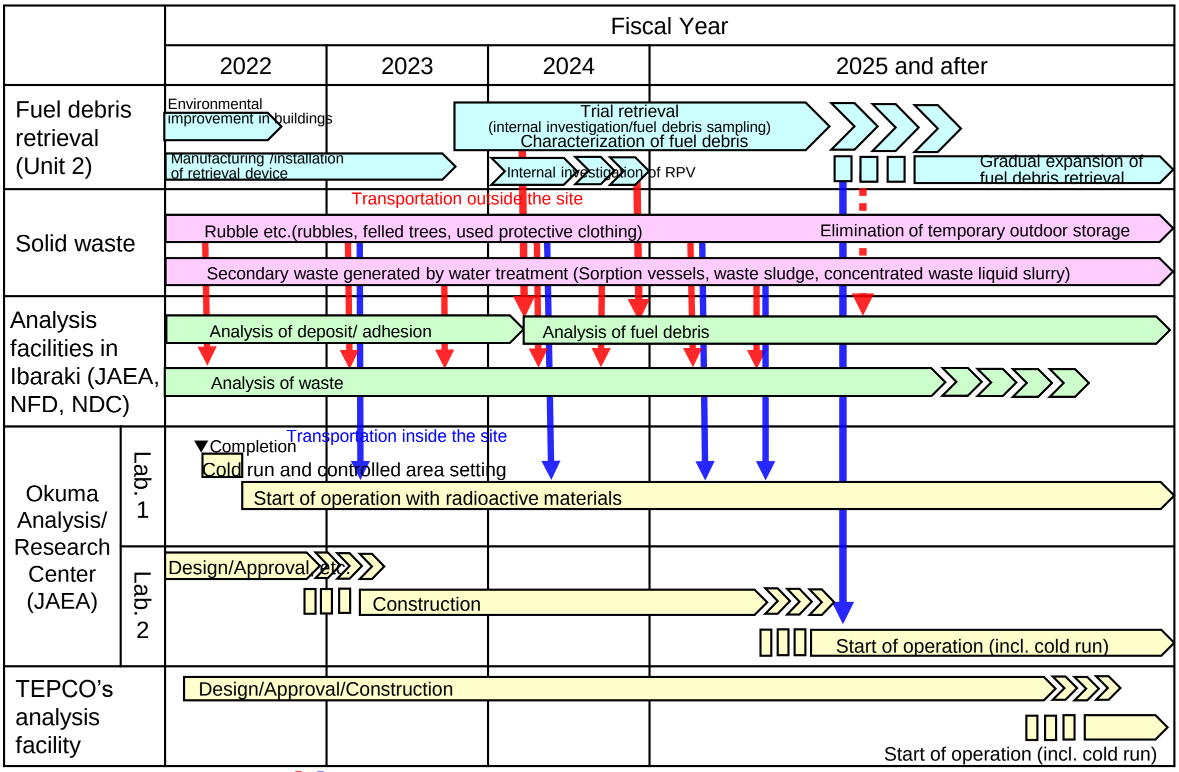
To safely and steadily proceed with decommissioning of the Fukushima Daiichi NPS, it is necessary for TEPCO to establish and develop facilities for analysis and the functions required for handling of solid waste or fuel debris. In addition, it is important to build a system that effectively utilizes analyzed results for each decommissioning operation.

In order to obtain good analysis results, it is effective to properly maintain ① the methods and systems for analysis, ② the quality of the analysis results, and ③ the size and quantity of sample.

4.3 Current status of establishing an analysis system and strategy

As an essential facility for decommissioning of the Fukushima Daiichi NPS, the JAEA is proceeding with the construction of Radioactive Material Analysis and Research Facilities adjacent to the Fukushima Daiichi NPS under the supplementary budget of the Government (FY2012). At commencing their operations, they will be designated as controlled areas of the Fukushima Daiichi NPS, which has the advantage that off-site transportation is not required. Leveraging this, it is effective to promptly identify basic physical properties, and incorporate them into safety assessment and work procedures. The objectives of laboratory-1 are solid waste analysis and third-party analysis of ALPS-treated water, and laboratory-2 is intended to conduct fuel debris analysis. The facility management building has been operating since 2018. The construction of laboratory-1 was completed in June 2022, and the controlled area and other areas were set as a part of the specified nuclear facility in October, then, analytical operation using radioactive materials has started. The laboratory-2 is in the process of screening application for approval of implementation plan changes and selecting the operator. TEPCO is also considering the construction of analysis facilities (comprehensive analytical facility) in response to the future needs of analysis including analysis of fuel debris and solid waste in addition to current routine.

As shown in Fig.20, since the laboratory-2 and the comprehensive facilities for analysis are scheduled to commence operation after the trial retrieval of fuel debris. Analysis will be conducted at the facilities for analysis in the Ibaraki area until the laboratory-2 is operational. Even after the operation commencement of the laboratory-2, if special techniques are required for sample pretreatment or if analysis and testing requires an extended period, it is more efficient to perform analysis in the Ibaraki area, because (i) there are many researchers and engineers, (ii) many types of special analysis devices are available, and (iii) there are a large number of hot cells with containment and shielding functions and application options, and to prioritize promptness on-site and adjacent areas of the Fukushima Daiichi NPS. As for solid waste analysis, as trial retrieval of fuel debris progresses, it is anticipated that solid waste that TEPCO has not had experience with previously, such as fine fuel debris and filters that have captured FPs, will be generated. Regarding high dose solid waste for which there is limited experience, it is desirable to analyze solid waste in the Ibaraki area for the same reasons as for the fuel debris described above, and it is necessary to continue it in the Ibaraki area for some time after the Laboratory-1 is put into operation. Based on the above, since target nuclides for permission for use and the situation with or without off-site transportation differ between facilities for analysis in the Fukushima Daiichi NPS site/adjacent areas and those in the Ibaraki area, it is effective to assign roles according to the characteristics shown in Fig. 21 and expand the analysis data of fuel debris and solid waste. However, since all the facilities for analysis in the Ibaraki area have been in operation for more than 30 years, considerations on measures are required for aging facilities that will be used continuously.



* indicates the place to be transferred to, but not corresponds to number of transfer.

* (dashed arrow) may change depending on the operation status of other facilities.

Fig.20 Construction and operation schedule for fuel debris retrieval and new analytical buildings

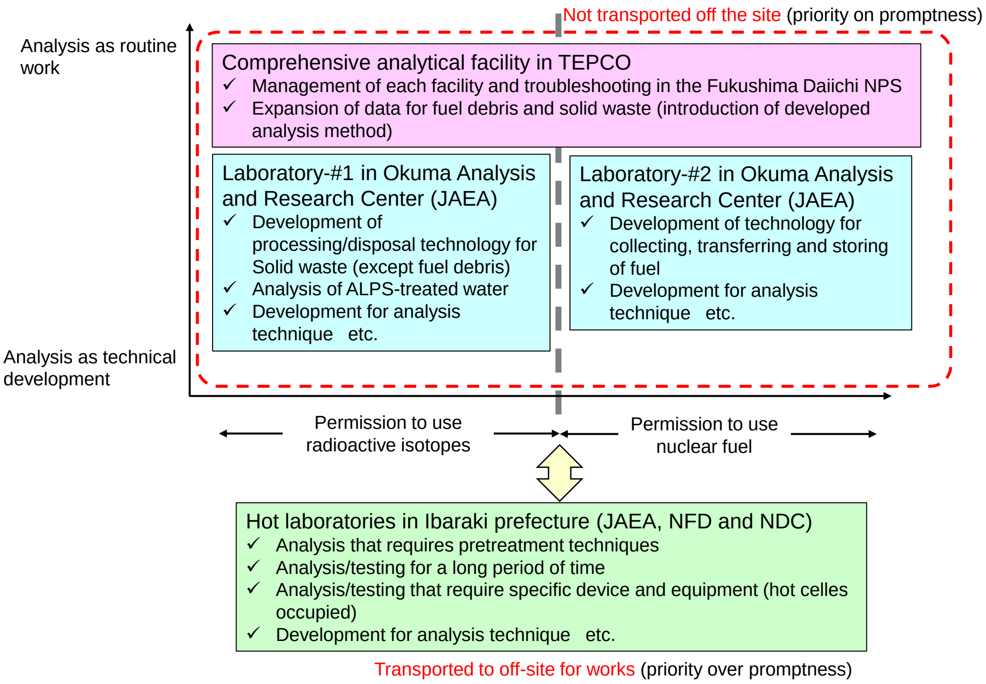


Fig.21 Characteristics and roles of each facility for analysis

Not only the facilities for analysis in the Ibaraki area, but also the Radioactive Material Analysis and Research Facilities to be operated in the area adjacent to the Fukushima Daiichi NPS are short of the human resources required to continue stable facility operation, and the securing and maintaining of analytical engineers needs to be considered. In this respect, it is necessary to consider in advance the qualities expected of analytical engineers in various analytical works, and to develop a plan so that the required roles are appropriately achieved. Since TEPCO must develop human resources for fields where there is little experience in as short a time as possible, it is important to effectively work on developing analytical technicians with the cooperation of the JAEA and Japan Nuclear Fuel Limited that have accumulated sufficient knowledge and experience on the handling of α-nuclides and fuel analysis techniques. Personnel exchanges between TEPCO and the JAEA and personnel acceptance from Nippon Nuclear Fuel Development Co., Ltd. (hereinafter referred as to as "NFD") to TEPCO have been ongoing.

4.4 Improvement of the quality of sample analysis results and use of non-destructive assay

4.4.1 Improvement of the quality of analysis results

Fuel debris contains difficult-to-measure nuclides, interfering elements, immiscible substances, etc., and there are problems in pretreatment and measurement, such as uniform dissolution of samples and selection of isobar. Therefore, it is considered difficult to identify and quantify all elements and isotopes down to trace components by analysis. It is also an important to have a skeptical point of view to the analytical result of the samples in consideration of the impact of the error factor. Monitoring data, sampling analyses, PCV internal/on-site investigation, analyses using SA codes, and past knowledge and experimental results have been accumulated. As part of verification of sample analysis results, through discussion and studies in light of existing findings, such as results of analysis, investigation and testing, deriving consistent property evaluations will improve reliability of analysis results, leading to higher quality of the analysis results.

To improve the analytical accuracy, the JAEA, the NFD, MHI Nuclear Development Corporation (hereinafter referred to as "NDC"), and Tohoku University have been cooperating to conduct chemical analysis and structural analysis using the same samples since FY 2020. Consideration is being given to analysis of TMI-2 debris in Ibaraki area offices using the latest technologies so as to expand the fuel debris data in future.

TEPCO and the JAEA are already cooperating in implementing forensic activities that estimate accident behavior and causes by comparing the results of sample analyses with simulation on progression of meltdown and past scientific knowledge. Furthermore, as an international forum, the BSAF, BSAF-2, PreADES, and ARC-F, which have been implemented as projects of the OECD/NEA, have come to an end, and the FACE project was launched in July 2022.

Since there are few personnel (analytical evaluators) who can design the analytical range and items in anticipation of how to use the analysis results in advance, it is also important to make efforts in increasing such personnel. Analytical evaluators are required to have the ability to (i) logically and accurately understand accident events from analytical results, (ii) appropriately incorporate the evaluation results into the areas required for the decommissioning process (retrieval method, safeguards, storage/management, and processing/disposal), and (iii) provide appropriate instructions for the following sampling. However, since it is difficult for individuals to address these all abilities, TEPCO should take the lead in organizing an analysis and evaluation team (One Team) by selecting researchers and engineers from domestic organizations with knowledge of fuel debris and decommissioning.

4.4.2 Sample analysis of fuel debris

The current sample analysis is mainly performed using electron microscopes after transporting smear samples to facilities for analysis in Ibaraki area. Since the density, hardness, and other items cannot be measured for micro or very small quantity of the samples, it is necessary to increase the size and quantity of the samples in accordance with the progress of the fuel debris retrieval process. Analysis is performed by using manipulators in analysis process in a hot cell, and in one facility, analysis of about 0.5 to 1 samples per month will be conducted. Further, the amount to be used in each hot cell is restricted for each nuclide that can be handled, and therefore, it is difficult to analyze a large number of samples. Consequently, there is a large gap between the volume to be retrieved/stored and the amount of samples for analysis.

Since fuel debris has heterogeneity, the analytical values vary depending on the sampled parts, and the situation is such that a sufficient amount of fuel debris cannot be analyzed, resulting in a range of uncertainty in evaluation. To increase the volume of good analytical results, regardless of the restrictions on improving analysis quality and sample quantity, it is effective to not only focus on increasing the volume in conventional sample analyses in hot laboratories but also to diversify and expand other analytical and measurement methods, understand the disadvantages and advantages of each item, and consider complementing them according to the intended use of the analytical results, for a comprehensive evaluation. Depending on the application, it may be worthwhile to consider methods that can only measure single items.

4.4.3 Use of sample analysis and non-destructive assay

One of the analysis and measurement methods that complements the results of sample analysis is to evaluate the amount of nuclear fuel without destroying the sample using radiation, quantum, etc. emitted, scattered, or transmitted from the sample (hereinafter referred to as "non-destructive assay.”). Table 2 shows the relative comparison of the items of sample analyses performed inside analysis facility and non-destructive assays performed out of the analysis facility and the number of samples. Sample analysis can perform many analysis tasks, but the time required for analysis is long, and the amount analyzed at one time is small. Although non-destructive assay can handle fewer items, the measurement time is shorter than that of sample analysis, and a larger quantity can be measured per measurement. Moreover, measurement can be performed with the object stored in a sealed container to prevent the spread of contamination.

Table 2　Relative comparison of key specifications in sample analysis performed in the analysis facility and non-destructive assay performed out of the analysis facility

	Analysis of samples performed in analysis facility*	Non-destructive assay performed out of analysis facility**
Time for analysis/ measurement	Long (△)	Short (○)
Items for analysis/ measurement	Many (◎)	Few (△)
Amount per analysis/ measurement	Small (△)	Large (◎)
Generation of liquid waste	Generated (△)	None (○)
Confinement during analysis and measurement	Unsealed	Unsealed or sealed
Dust prevention	Necessary	Necessary
Radiation shielding facility	Necessary	Necessary

◎ : Excellent　　○ : Good　　△ : Acceptable

* : The analysis will be conducted in a facility dedicated to analysis, such as a hot laboratory suitable for dealing with fuel debris samples.

** : The facility will be used in the process from retrieving to storing fuel debris. The analysis will be conducted in a facility not dedicated to analysis.

In addition to sample analysis in the analysis facility, if non-destructive assay limited to specific items, such as quantitative nuclear fuel, is measured in the fuel debris containers, and it would compensate for the small number of analyses and enable rapid determination of the amount of nuclear fuel in the fuel debris. This will make it possible to maintain the subcritical state and move on to the next process. At this time, it is desirable to keep the range of uncertainty in the properties of fuel debris as small as possible while increasing information about the sample, including the number of sample analyses and the coordinate information at the time of sample collection, to improve the reliability of the data. In order to improve the accuracy of fuel debris characterization and the safety in storing retrieved fuel debris, specific application methods of non-destructive assay should be studied at the facilities used in the process from retrieval to storage of fuel debris.

5. Efforts to facilitate research and development

5.1 Significance and the current status of research and development

There are many difficult technical issues requiring research and development to promote the decommissioning of the Fukushima Daiichi NPS from the perspectives of safe, proven, efficient, timely, and field-oriented. At present, when trial retrieval of fuel debris is about to begin shortly, it is necessary to accelerate research and development in consideration of the practical application for a gradual expansion of fuel debris retrieval and further expansion of fuel debris retrieval in scale. In order to solve these technical issues, decommissioning research and development is being performed by various industrial-academic-governmental institutions.

For application research and practical application research for decommissioning, the Government provides supports the R&D carried out by each organization to solve issues of highly-difficult ones through "the Project of Decommissioning and Contaminated/Treated Water Management", and to promote basic and fundamental research and human resource development by universities and research institutes in Japan and overseas through "The Nuclear Energy Science & Technology and Human Resource Development Project (hereinafter referred to as "World Intelligence Project")". TEPCO is engaged in technical development directly leads to practical application. NDF considers R&D medium-to-long term plans, next-term R&D plans, and supports the World Intelligence Project. With institutes involved as its members, moreover, NDF established the Decommissioning R&D Partnership Council, which considers issues on information sharing on needs and seeds for R&D, coordination of R&D in line with the needs of decommissioning work, and promoting cooperation in R&D and human resource development.

From FY 2022, JAEA plans to implement actions in accordance with the Phase 4 medium-to-long-term goals and plans. It is expected that JAEA will leverage its knowledge and experience in R&D related to decommissioning of the Fukushima Daiichi NPS and play a significant role in initiatives for characterization of fuel debris and R&D for waste management and analysis. The R&D implementation system is shown in Fig. .

The R&D fields to be conducted at “the Fukushima International Research and Education Center”, that will be established by the government in April 2023, are ① robots, ② agriculture, forestry and fisheries, ③ energy, ④ radiation science, drug discovery and medical care, and industrial use of radiation, and ⑤ collection and dissemination of data and knowledge on nuclear disasters, and collaboration in R&D related to decommissioning is also expected. Therefore, NDF will consider collaboration in the future with a view to outreach activities related to this Center’s R&D, while also taking into account the basic plan[6] for the promotion of R&D[7].

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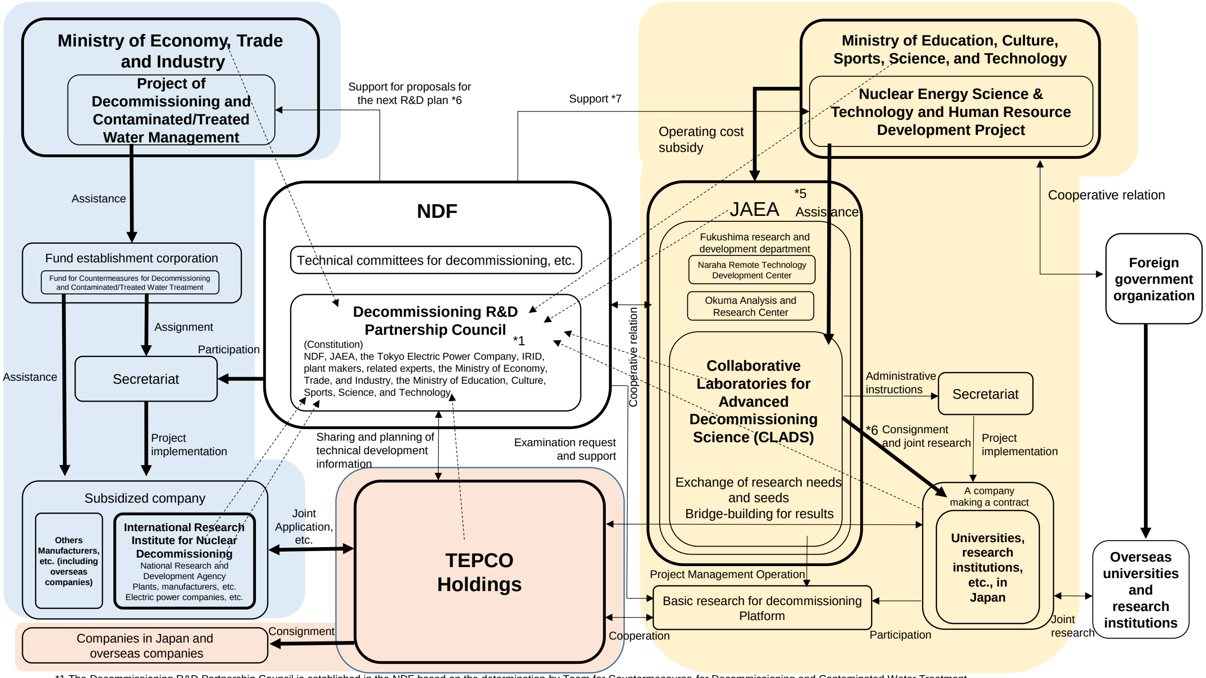
6 Basic Plan for Research and Development for new industry creation (Provided by Cabinet Office, Government of Japan, August 26, 2022)

7 Basic Concept for the Fukushima International Research and Education Center (Provided by Reconstruction Promotion Council, March 29, 2022)



*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 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.
*3 Some organizations such as JAEA are located at two or more places.
*4 Each organization has cooperative relations with foreign organizations based on MOU, etc., respectively.
*5 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.
*6 With regard to the Government-led Project of Decommissioning and Contaminated/Treated 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.
*7 The NDF participates as a member in a steering committee of the World Intelligence Project for Nuclear S&T and Human Resource Development.

Fig. 22 Overview of the R&D implementation system related to the decommissioning of Fukushima Daiichi NPS

5.2 Key issues and strategies

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

In FY 2020, NDF and TEPCO developed the R&D medium-to-long-term plan overlooking the overall research and development for about ten years for decommissioning and have updated it every fiscal year since then. The R&D medium-to-long-term plan will be updated based on the revised Mid-and-Long-term Decommissioning Action Plan of TEPCO, the concept study for further expansion of fuel debris retrieval in scale, and the progress in ongoing R&D.

In reviewing the R&D mid-and-long-term plan, TEPCO, Ministry of Education, Culture, Sports, Science and Technology, Ministry of Economy, Trade and Industry, and NDF have participated in the R&D planning meeting. Based on the discussions at the 10th Decommissioning R&D Partnership Council held in February 2022, TEPCO, JAEA/CLADS, and NDF jointly analyzed and shared technical issues, including long-term issues exceeding ten years, to promote collaboration between the World Intelligence Project and The Project of Decommissioning, Contaminated Water and Treated Water Management, and have reviewed issues comprehensively and exhaustively. The results will be incorporated into the R&D medium-to-long-term plan and the overall map of the basic/fundamental research for reference.

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

5.2.2.1 The Project of Decommissioning, Contaminated Water and Treated Water Management

The Ministry of Economy, Trade and Industry is providing support through The Project of Decommissioning, Contaminated Water and Treated Water Management to solve technically challenging issues for decommissioning.

In the Project, since 2020, NDF has been participating in the secretariat to strengthen the functions of project planning and progress management, while TEPCO jointly applies for issuance in cooperation with research leadership and provides project management to incorporate requirements in terms of actual site applicability.

This enhanced functionality has enabled the Secretariat to follow the progress of R&D, leading to the smooth execution of projects and achieving intended results. In addition, TEPCO's needs in terms of actual site applicability have been incorporated into the Project, and the positioning of the Project in TEPCO's engineering schedule has been clarified.

5.2.2.2 Next-term R&D Plan

In order to support the Project, and based on the R&D medium-and-long-term plan, every fiscal year, NDF is formulating the next-term R&D plan as the R&D to be carried out over the next two years. The next-term R&D plan aims to solve issues related to fuel debris retrieval and processing/disposal of solid waste.

After adjustment and discussion with parties concerned at R&D planning meetings, the next-term R&D plan is first deliberated on by the Fuel Debris Retrieval Expert Committee and Waste Management Expert Committee, which are the committees at NDF, and then by the Decommissioning Strategy Committee. After this, it is summarized as an NDF proposal. This plan was reported by the Ministry of Economy, Trade and Industry (METI) to the Team Meeting for Decommissioning and Contaminated Water/Treated Water Management/Secretariat Meeting, and the Project has been implemented accordingly.

In considering the next-term R&D plan, the R&D results have been evaluated to identify issues whose level of achievement should be improved and emerging issues, as well as to identify new challenges and organize technical issues with a view of the R&D medium-and-long-term plan. When identifying issues, it is also important to identify them exhaustively, confirm whether each issue is in line with the needs of TEPCO as the entity responsible for decommissioning, and aim for R&D results to be utilized for TEPCO's engineering.

In FY 2022, as a new initiative to develop the next-term R&D plan, a request for information (RFI) was made to widely solicit information on technical issues to be resolved toward the decommissioning of the Fukushima Daiichi NPS. In order to contribute to the consideration of the next R&D plan, this is a request for the public to provide information on R&D themes, details of

R&D (technical issues to be resolved and details of implementation), scale of R&D, potential joint R&D destinations, and R&D fields.

5.2.2.3 Further research and development implementation system for The Project of Decommissioning, Contaminated Water and Treated Water Management

The IRID has played a major role in research and development for decommissioning for about eleven years since the time that the post-accident situation inside the reactors was unknown. In particular, the IRID has established a good track record in internal PCV condition analysis through its internal investigations, as well as development of analytical and estimation techniques for characterization of fuel debris, development of fuel debris retrieval equipment and storage containers, and development of processing/disposal technologies for solid waste.

Meanwhile, as the engineering work by TEPCO progresses, the situation in the reactors and the needs are gradually becoming clear. In addition, development is currently being promoted based on the engineering work by TEPCO, which is a shift from joint activities through the Collaborative Innovation Partnership. In light of changing environment, consideration is being given to a R&D structure in preparation for IRID's current continuity deadline after summer 2023.

Since it is still important to review R&D tasks from a broad perspective in The Project of Decommissioning, Contaminated Water and Treated Water Management, evaluate the Project in terms of actual site applicability and incorporate them into R&D. Accordingly, NDF plans to further strengthen and restructure the functions related to R&D planning and proposals and efforts to ensure operation quality in cooperation with TEPCO and other organizations concerned. On the other hand, for the projects that need to be succeeded to in the Project, the following issues must be addressed if projects are to be implemented smoothly so as not to cause any problems, and discussions are being carried out by relevant organizations.

- The project executor when taking over the Project
- Appropriate succession of hardware (tangible assets e.g. facilities and equipment) and software (intangible assets e.g. result products and technical information) necessary to continue R&D
- How to maintain and utilize the know-how accumulated by the subsidized projects

Regarding the outcome of the development that has been conducted through the Project, since the decommissioning of the Fukushima Daiichi NPS is a national/social issue, it is important to establish an easily accessible structure where organizations involved in the research and development for decommissioning can make effective use of the R&D results, including knowledge obtained. Therefore, it is recommended that archiving in terms of information disclosure and knowledge sharing is promoted. In this case, the issues are to establish rules for the compilation and sharing of archival materials, establish a framework for the establishment/management of archival materials, and develop the management tools to be used.

TEPCO should be fully aware of the significance and role of each R&D project in all R&D activities, from basic/fundamental research to practical application research. Then, while being involved in R&D appropriately, under the management of the technology development by the D&D Research & Development Center, TEPCO needs to be committed to decommissioning research more proactively including independent technology development by TEPCO. In doing so, it is necessary to collaborate with the *Toso Mirai Technology Company* (hereinafter referred to as "the new engineering company" established in October 2022.

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

5.2.3.1 The Nuclear Energy Science & Technology and Human Resource Development Project

As the World Intelligence Project, the MEXT has been promoting fundamental/basic research and human resource development activities, which contribute to solving issues such as decommissioning of the Fukushima Daiichi NPS. The project is bringing together domestic and overseas intelligence from universities/researching institutions, crossing barriers of the nuclear field, and through close coordination and alignment including international joint research. JAEA/CLADS implements this World Intelligence Project to strengthen cooperation between JAEA/CLADS and universities, and establish a system to implement medium-and-long term R&D and human resource development, contributing to decommissioning more stably and continuously.

In soliciting applications for the current World Intelligence Project, JAEA/CLADS is using the "overall map of the basic/fundamental research", which provides an overview of the entire decommissioning process from contaminated water management to waste processing/disposal, and identifies the R&D needs and seeds required. Since FY 2021, efforts have been made to match decommissioning needs with research seeds, such as holding workshops with the participation of TEPCO and companies involved in decommissioning. From FY 2022, the plan is to introduce Research Supporters (RS) to maximize the use and outcomes of the results at the decommissioning sites.

It is an important issue to directly apply the results of some basic/fundamental research contributing to problem-solving in on-site decommissioning, and it is important to promote better matching needs from decommissioning site with seeds at universities/researching institutions and serve as a bridge to share outstanding research results obtained mainly in the World Intelligence Project.

5.2.3.2 Collaboration between The Project of Decommissioning, Contaminated Water and Treated Water Management and the World Intelligence Project, and initiatives for business-academia collaboration by TEPCO

To deepen the matching between needs and seeds and implement R&D for decommissioning consistently from basic/fundamental research to applied practical application research, it is essential to promote collaboration between The Project of Decommissioning, Contaminated Water and Treated Water Management and the World Intelligence Project. For that purpose, NDF and organizations concerned should actively exchange and share information on the results of each project and work together on the use of the Decommissioning R&D Partnership Council and initiatives to share future directions and issues shared at the Meeting.

TEPCO is also engaged in industry-academia collaboration efforts with universities (The University of Tokyo, Tokyo Institute of Technology, Tohoku University, and Fukushima University) to unearth technological seeds that meet needs useful for decommissioning from a wide range of research resources at universities, not only in the nuclear field but also in the basic/fundamental research field.

The Government, JAEA/CLADS, NDF, TEPCO, and other organizations involved need to further strengthen their cooperation for better matching needs with seeds and serve as a bridge to share outcomes.

5.2.3.3 Establishment of the centers of basic research/research infrastructure

In order to make the long-term decommissioning of the Fukushima Daiichi NPS proceed steadier in technical aspects, it is essential to work on developing R&D infrastructure and accumulate technological knowledge, develop fundamental technologies and collect basic data, building up research centers, facilities and equipment, and human resource development. R&D for the decommissioning of the Fukushima Daiichi NPS is an opportunity to practice state-of-art science and technology and the accumulation of such activities is expected to become a source of innovation.

The Collaborative Laboratories for Advanced Decommissioning Science of JAEA/CLADS (Tomioka-machi, Fukushima Prefecture) is working to enhance the base functions of JAEA/CLADS by establishing a network of universities, researching institutions, and industry in Japan and overseas to promote the R&D and human resource development in an integrated manner, establishing the “Decommissioning research program based on development of research human resources” in the World Intelligence Project, and starting the research, development, and human resource development projects that connect organizations through a cross-appointment system after the establishment of a research/human resource development base (collaborative lab).

For research and development infrastructures as hardware, development and utilization of the Naraha Center for Remote Control Technology Development of JAEA and maintenance of the JAEA Okuma Analysis and Research Center (Radioactive Material Analysis and Research Facility) are ongoing. In FY 2022, the Naraha Center for Remote Control Technology Development plans to conduct a mock-up test of a device for trial fuel debris retrieval, and the Okuma Analysis and Research Center has started the operation of Laboratory #1 of its analysis and research facility for waste analysis.

6. Activities to support our technical strategy

6.1 Further strengthening of project management and improvement of capability required as a decommissioning executor

6.1.1 Significance and current status of project management

In order to smoothly proceed with the entire decommissioning project while harmonizing, it is necessary to establish a management system in which the organizations involved in the project work together to achieve the goals and enhance their overall capabilities.

The individual work in each work area of a decommissioning project generally proceeds through the following processes: conceptual design, research and development, basic design, detailed design, manufacturing, on-site installation, inspection, and operation. In addition, the NRA will conduct reviews and inspections, as necessary. In order to carry out such a series of processes without omission or delay, it is effective to set up the major workflow defined in the long-term plan as individual projects, which are management units of an appropriate scale. It is then important to optimize the interrelationships and chronological relationships among the projects, and to proceed with overall consistency under a sophisticated project management system so that the risks inherent in the projects can be appropriately managed. From this perspective, TEPCO has been working to build and strengthen its project management system, which was reorganized in April 2020. Project-based organization management has been gradually established through two years of operation.

As difficult projects such as fuel debris retrieval will be implemented at full-scale in the future, and TEPCO intends to take the lead in EPC[8] management, further enhancement of project management capabilities is required.

As the decommissioning work is well underway, entering Phase 3 of the Mid-and-Long-term Roadmap, it is anticipated that the projects to be handled will become more diverse, and interface management between projects will become more complex, further increasing the level of project difficulty. As a result, TEPCO's workload for project management is also expected to increase. Leadership of the TEPCO management will become even more critical in securing personnel over the long term, for example, by prioritizing work and peak work shifting to equalize the workload and increasing the number of personnel if the workload still cannot be supported.

Examples of key initiatives up to FY 2022 include: strengthening the authority of project managers through organizational restructuring, process management using dedicated software (P6), establishing and operating a risk monitoring system (risks are quantified using risk management sheet - risks are mapped on two axes, frequency of occurrence and impact, and risk trends are monitored regularly at meetings with the management's attendance.), strengthening project management based on partnership agreements with overseas companies with knowledge

[8] E: Engineering, P:Procurement, C:Construction

and experience in decommissioning projects, improving the level of safety and quality, and development of a forward-looking plan (Mid-and-Long-term Decommissioning Action Plan) .

6.1.2 Key issues and strategies to be strengthened in the future

6.1.2.1 Safety and Operator's Perspectives and promulgating the "Safety First"

In April 2021, TEPCO received an order from the Nuclear Regulation Authority (NRA) to prohibit the transfer of specified nuclear fuel materials due to non-conformities in the protection of nuclear materials at the Kashiwazaki-Kariwa Nuclear Power Station (hereinafter referred to as "Kashiwazaki-Kariwa"). As a result, TEPCO's nuclear regulatory inspection response category became Category 4 ("the objectives of the activities in each monitoring area are satisfied, but there is a prolonged or significant deterioration in the safety activities conducted by the operator"), and many inspections will now be conducted under the supervision of the NRA.

The operation of Fukushima Daiichi NPS differs from that of the Kashiwazaki Kariwa in terms of the form of business, and as for the management system, the full-scale project management has been implemented in the Fukushima Daiichi, which is also different compared to Kashiwazaki-Kariwa. In February 2022, on the other hand, a non-conformance event occurred, where information on the failure of the seismometer installed on a trial basis in the Unit 3 reactor building of the Fukushima Daiichi NPS was not shared within the organization, and it was not fixed/restored for a long period of time. Although there were no issues with work safety or exposure, etc., a series of events are receiving severe external criticism. At the Fukushima Daiichi NPS, the management themselves are engaged in conversation with all site personnel to understand the organizational issues behind the events.

In order to establish safety as part of the organizational culture, so that is not just a slogan, it is insufficient to just ask employees to prepare themselves, and instead each and every employee needs educational materials and opportunities to learn about safety in a systematic way. Moreover, to regain the trust of the public, it is important for TEPCO to continuously improve and promote measures for preventing nonconformities, especially those that could lead to environmental impacts, personal injury, and radiation dispersion, as well as to disseminate information and build systems that incorporate the perspective of the local community. Frequent occupational accidents, human errors (HEs), and system failures will cause the community and society to lose trust. Especially with respect to occupational accidents, since many workers at Fukushima Daiichi are local resident, continued occupational accidents can cause anxiety not only for on-site workers but also for their families. Ensuring “a safe workplace” is the responsibility of the owner. TEPCO will further refine its on-site capabilities as an owner and aim for a "three zeros" workplace with zero occupational accidents, zero HEs, and zero system failures.

6.1.2.2 Owner's engineering capability

In projects with mature technology, precise performance requirements, and large scale, such as the construction of nuclear power plants, waterfall engineering[9] is usually used. However, since fuel debris retrieval is an approach in which no one has experience, the target settings and required specifications from TEPCO, the executor of the decommissioning project, are not always clear when undertaking engineering work, and the degree of performance requirement settings, physical feasibility of methods and equipment, and performance assurance must be through trial and error. Therefore, in addition to “the sequential approach” that addresses “work in the initial stage” and then rolls out the information gained to the next stage, the operation executor’s performance requirements, the establishment of the supply chain functions, and its engineering process should be iteration approach-based[10], to some extent.

In iterative engineering, the contract between the project executor and the supply chain is not conventional, so TEPCO, as a project executor, is strongly required to "make a judgment on engineering and is responsible for the results”. To achieve this, as the project executor, TEPCO as the owner must improve its owner engineering capability. The owner's engineering capability here refers to the capability required of TEPCO itself as a site owner[11] and a license holder, specifically, it is a capability that consists of both project management capability and technical capabilities based on safety and operator’s perspectives.

Fuel debris retrieval, in which the applicable technology, environment, and target objects are all unknown, is not work like designing and constructing a nuclear power plant, where the finished product is delivered with a performance guarantee. Therefore, unless TEPCO, the executor of the project, bears the business and technical risks ultimately, there is a risk that the performance requirements will be unlimited.

(1) Project management capability

The decommissioning of the Fukushima Daiichi NPS must be carried out reliably over a long period of time under changing site conditions, and it will be difficult to cope with conventional contracts, especially for high-risk project work such as fuel debris retrieval. Therefore, it is necessary to prepare a contract method based on a new concept, in which both the contractor and the recipient cooperate, share the contractual risks, and aim for the agreed-upon goals. In terms of procurement, instead of one-way “Buying” from an ordering party to an order-receiving party, both

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[9] It is a method of increasing the accuracy of the design in stages, from conceptual study to basic design and then to detailed design. Since the process proceeds in a single direction from upstream to downstream, it has the advantage of easy control of budget, process and resources (personnel), but it also has the disadvantage of not being able to go back once the next phase is underway. It is called the waterfall type, because it resembles a waterfall where water falls from the top to the bottom.

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

[11] An owner here has three positions of 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)

parties should bear in mind the concept of "Acquisition" of the final result by "Making", with consideration of all steps from development, manufacturing, to even operation/maintenance.

To deal with such Making-based projects, in addition to improving the engineering capability, such as the ability to materialize specifications, it is necessary to have project management capability with a focus on "Acquisition of the final result".

Based on the shared awareness that conventional Buying-oriented project management alone is not enough to properly control projects with large uncertainties such as fuel debris retrieval, TEPCO and NDF are benchmarking the acquisition management[12,13] as adopted by the U.S. federal government as a precedent to further develop current project, and are actively learning the methodology with the cooperation of external experts starting from FY2017, and currently customizing it to fit the decommissioning project of the Fukushima Daiichi NPS.

(2) Engineering capability based on safety and operator's perspectives

In the past, the construction of nuclear power plants was achieved on-time, on-budget, and on-performance by placing bulk orders with companies with extensive construction experience. However, no company has experienced the decommissioning of a plant that has experienced a meltdown like the Fukushima Daiichi NPS. Especially, fuel debris retrieval is extremely technically challenging, and it is not easy to accomplish with only one company's technology. It is necessary to call upon each company's unique and top technologies and establish a single system. To achieve this, TEPCO must have more technological capabilities than before, i.e., the engineering capabilities being able to judge the merits and demerits of individual technologies ("insight") and then integrate them into a system to achieve the desired performance. Through the insourcing that they are promoting, TEPCO aims to improve its ability to make engineering judgments on individual technologies, enhance capabilities for integration as a system, and reduce technical risks.

In addition, the situation of Fukushima Daiichi NPS has changed significantly from before the accident, so the ability to think about things from the perspective of the site (on-site capability) is particularly important. Specifically, the following capabilities should be developed based on a thorough knowledge of the functions and performance of the equipment to be acquired;

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[12] Acquisition management is a project management method adopted (and legislated) in the U.S. federal government budgeting process in the 1990s and has been continuously improved. It aims at acquiring outcomes (products, structures, and deliverables) using scientific and systematic management techniques based on reliable data. This method differs significantly from conventional in that it breaks down work in the Work Breakdown Structure (WBS) into the elements of outcomes (products, structures, and deliverables) to be obtained rather than tasks. In addition, by accumulating the costs of each decomposed element based on the planning process and visualizing the progress of the project, it becomes possible to appropriately identify the gap between the plan and the actual situation, to grasp the risk at an early stage, and to take countermeasures.

[13] In acquisition management, acquisition and procurement are defined as follows and adequately used depending on the case. Acquisition refers to acquiring the value and capability related to specific equipment and other deliverables throughout their lifecycle, from development, manufacturing, and operation to maintenance, to achieve a specific goal or objective. However, a part of this acquisition flow is sometimes contracted to an external organization at each phase, such as development and manufacturing, and the gaining of specific elements on this contract basis is called procurement. In other words, acquisition consists of several procurements (deliverables based on contracts).

・in the design phase, ability to develop specifications to ensure that a given function can be performed over its life cycle (from installation, verification, operation to maintenance) under on-site operating conditions (operating environment, with/without interfering objects, etc.),

・in the on-site operation phase, ability to assess the latest on-site conditions, identify potential risks (e.g., accidents involving personnel, procedural errors, etc.) in conjunction with the contractor, and take appropriate risk measures to ensure safety and quality on the operation site, and

・in the event of an emergency, ability to troubleshoot problems by TEPCO employees themselves, even without support from partner companies.

6.1.2.3 Securing and developing human resources

6.1.2.3.1 Securing and developing human resources for smooth implementation of decommissioning projects

In addition to the fact that the decommissioning project of the Fukushima Daiichi NPS is an unprecedented task for which nobody has experience, it is necessary to systematically secure and develop human resources in anticipation of the expansion of operations in line with the progress of the fuel debris retrieval plan. Specifically, based on the Mid-and-Long-term Decommissioning Action Plan and mid-to-long-term business outlook with a view to subsequent business development, it is desirable to develop a staffing plan that includes the required skills and qualities and headcount as well as an organizational development plan that outlines tactics to achieve them, and implement measures to increase personnel motivation. Of these, human resource development is particularly time-consuming. Thus, it is also necessary to reduce inefficient operations and use limited human resources effectively. In the future, a higher level of engineering and expertise will be required to achieve more technically challenging goals than in the past, such as selecting methods for fuel debris retrieval and designing new systems and facilities. Therefore, in the mid-to-long-term staffing plan, it is desirable to anticipate the required headcount in each technical field and when they are needed, including personnel with more advanced expertise in addition to those in each job category that will be needed in the future.

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

In order to continue decommissioning of the Fukushima Daiichi NPS for a long period of time and to continue R&D activities necessary for that, it is essential to train and secure future researchers and engineers, and ensure technical transfer, as well as it is important for industrial-academic-governmental institutions, as a whole, to steadily promote efforts according to each level of higher and secondary education.

For students in higher education, it is fundamentally important for the industry and higher education institutions to cooperate and continuously implement activities to promote understanding of the nuclear industry, and constantly produce young researchers/engineers from these higher education institutions. In particular, the World Intelligence Project by MEXT and JAEA/CLADS has introduced a system in which students and young researchers are made to be aware of decommissioning as an important research area, and is engaged in decommissioning research. The World Intelligence Project's mechanism and implementation have produced some results, and human resources have been activated, with graduates being engaged in decommissioning-related projects. Hereafter, it is important to implement this project so that the perspectives of decommissioning sites in TEPCO and those of the activities in higher education institutions can be more aligned.

For students in the stage of secondary education, it is important to introduce appealing points of engaging in the nuclear field including decommissioning, and to make efforts to attract their technical interests with a focus on decommissioning, as well as to increase their understanding of decommissioning and reconstruction of Fukushima Daiichi NPS, and in a broad sense, of the career path in science and technology fields. In addition, NDF hosts "student sessions" for high school students, etc., to give thought to the reconstruction of Fukushima along with the International Forum on the Decommissioning of the Fukushima Daiichi NPS (hereinafter referred to as "International Forum"). In 2022, as in 2021, workshops are being held to discuss a vision of the future in the Futaba area in 2050, based on prospects derived from statistical data on the Futaba area, the status and plans for decommissioning, and information on human and natural resources in the entire Hamadori area. Through these efforts, high school students are given an opportunity to think about activities to achieve both decommissioning of the Fukushima Daiichi NPS and reconstruction, enabling them to increase their awareness that decommissioning is an important issue in reconstruction of local communities, and foster interest in and willingness to contribute to decommissioning and reconstruction efforts. Such activities have achieved some positive results.

Institutions concerned are continuously required to promote and strengthen their efforts to secure and develop human resources for the next generation according to their respective roles and levels.

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

It is important for many citizens and local residents to acquire basic knowledge of the accident and decommissioning, disaster response, radiation safety, and food safety related to the Fukushima Daiichi NPS from the perspective of future resilience of the whole country. This is because it will serve as basis for discussions on decommissioning, and related radiation safety, etc., based on accurate information and for promoting public understanding. In addition, although it is not directly aimed at fostering human resources who will play a leading role in the nuclear field in the next generation, it is also an aspect of indirectly broadening the range of human resources who are interested in not only in the nuclear field but in science in general. Particularly in the field of nuclear energy, it is necessary to learn about the relationships in local communities and society through various opportunities according to the development stage of children, as well as to acquire knowledge and experience on nuclear energy and decommissioning. To do so, since it is important that children take an interest through the knowledge and experiences of adults around them, such as teachers and parents. Therefore, it is important to further spread knowledge on nuclear energy and decommissioning based on scientific evidence, which to a wide range of people including those involved in primary education institutions. In this regard, the government is promoting the continuous expansion of on-site classes and the facilitation of the use of supplement books about radiation, based on the “Action Plan for the Steady Implementation of the Basic Policy on the Disposal of ALPS-treated water” (formulated on December 28, 2021, and revised in August 30, 2022). NDF also holds workshops for local students to discuss decommissioning and reconstruction as described above.

6.2 Strengthening international cooperation

6.2.1 Significance and the current status of international cooperation

In recent years, nuclear reactors and nuclear fuel cycle-related facilities built at the dawn of the use of nuclear energy have reached the end of their operational life, and decommissioning of these facilities is in full swing in many countries. Each country continues to face challenges such as technical difficulties what is called "unknown unknowns (don't know what we don't know)", long-term project management, and securing large amounts of funding.

In order to steadily proceed with the decommissioning of the Fukushima Daiichi NPS, which deals with difficult engineering issues, it is important to learn lessons from precedent decommissioning activities, etc. and apply them to the decommissioning of the plant as a risk reduction strategy, and to utilize the world's highest level of technology and human resources, i.e., to gather and utilize the wisdom of the world.

To bring together the wisdom of the world, it is important to maintain and develop the international community's continuous understanding, interest, and cooperation in decommissioning. Therefore, it is important to promote decommissioning in a mutually beneficial manner that is open to the international community by gaining the trust of the international community and disseminating accurate information on the progress of decommissioning, etc., and by actively and strategically returning to the international community the knowledge and other findings gained through the accident at the Fukushima Daiichi NPS and decommissioning.

Specifically, it is important to promote bilateral cooperation in line with the circumstances of each country and to utilize the framework of multilateral cooperation through the IAEA and OECD/NEA. Japan has been holding an annual dialogue and establishing a conference body to share information with other countries as an intergovernmental framework. Moreover, each of the relevant domestic organizations has concluded cooperative agreements and arrangements with relevant overseas organizations, and has disseminated information at international conferences. NDF has been working on disseminating information on decommissioning through speaking at major international conferences. By securing the trust of the international community and promoting mutually beneficial decommissioning, we are trying to maintain and develop the international community's continuous understanding and interest as well as cooperative relationships.

In addition, in the course of the above-mentioned international cooperation, due to the global outbreak of COVID-19, many meetings and events related to IAEA, OECD/NEA, etc. are held online. NDF has also been actively utilizing the online systems and other means and ensuring continuous opportunities for information exchange to gather the world's wisdom, maintain and enhance the international society's continuous understanding and interest, and maintain and develop cooperative relationships with international community, such as the exchange of views with invited overseas experts in previous years and the holding of annual meetings with decommissioning-related organizations in other countries online. In the future, it is important to further expand the opportunities for communication with other countries by taking advantage of the experience gained so far.

6.2.2 Key issues and strategies

6.2.2.1 Integrating and giving back the wisdom and knowledge from around the world

In moving forward with decommissioning, Japan has received various kinds of assistance from foreign governmental organizations and experts, through the dissemination of information on issues related to decommissioning to the international community and participation in international joint activities. About eleven years have passed since the accident, and it is important to deepen the mutually beneficial relationship while also working to return the know-how and lessons accumulated so far to the international community. The situation of the Fukushima Daiichi NPS and the knowledge obtained have been disseminated through the international joint activities and conferences mentioned above, and it is necessary to promote these activities continuously. In addition, it is desirable for Japan to actively provide information on the accident at the Fukushima Daiichi NPS, activities, and achievements toward decommissioning to countries other than advanced nuclear nations in cooperation with international organizations.

The difficulty in traveling to and from other countries due to the pandemic outbreak of COVID-19 is an obstacle to the continuation and enhancement of such mutually beneficial relationships. However, it is important to secure opportunities for communication and work to maintain and develop relationships by utilizing online systems and other means so that the unprecedented situation, not limited to the COVID-19, does not dilute relationships with relevant organizations, experts, and international organizations in other countries.

In addition to disseminating information on the current status and challenges of the decommissioning to the world through a series of the International Forums, NDF has collected the wisdom including lessons learned and technologies derived from decommissioning around the world,. It is important to continue to make the International Forum an effective opportunity to gather and return wisdom from all over the world by using the online system, even in the situation where direct participation from other countries is difficult. On the other hand, in light of the epidemic situation of the COVID-19and possible changes in the way measures are taken to prevent the spread of infection, NDF will gather and return wisdom and knowledge by using effective methods with a view to proactively securing opportunities for face-to-face communication.

As the engineering of Fukushima Daiichi NPS is in full swing, it is important to grasp the latest status of excellent technologies and human resources in the world and to utilize them effectively. In this context, TEPCO has been actively engaged in technological exchanges with overseas private companies. For instance, the robot arm for the trial retrieval of fuel debris from Unit 2 was developed by a British company and is currently undergoing training in Japan. It is necessary for TEPCO to continue to keep abreast of the latest information from around the world, including the situation in the private sector, and to engage in continuous communication with these private companies, sharing information on the progress of decommissioning work and forming an environment in which the necessary technologies can be accessed when needed.

6.2.2.2 Maintaining and developing the international community's understanding of and interest in decommissioning and cooperative relationships

In order to mobilize the wisdom of the world for the decommissioning of the Fukushima Daiichi NPS, it is important to maintain and develop the understanding, interest, and cooperative relationship of the international community. Until now, an online system has been used to maintain exchange opportunities. However, considering that the face-to-face activities of the international community is returning, it is essential to maintain and develop cooperative relationships with relevant organizations and international organizations, with a view to restoring face-to-face interactions as well as online exchanges.

It is important for the government and other domestic organizations to ensure transparency of information on decommissioning and continuously disseminate accurate information in order to maintain, increase understanding of the international community, and build a trusting relationship. Regarding information dissemination, about eleven years have passed since the accident, the interests of the recipients of the information have changed since the time of the accident, and there are some gaps between countries in the amount of knowledge and information that are the base of understanding. For this reason, consideration should be given to providing easy-to-understand information not only for experts but also for non-experts, devising ways of providing explanations that consider the level of understanding of the recipients by effectively using videos and illustrations and disseminating information in languages other than Japanese and English. It is also important to deepen the understanding of information recipients by disseminating and accurately visualizing information on the current status and issues related to decommissioning, paying attention to their level of interest and understanding, as this will eventually lead to building a trusting relationship.

In this way, in participating in international joint activities, with the steady implementation of decommissioning, which is Japan’s top priority, as a premise, it is necessary to work in such a way that the interests of the international community can also be secured. Disseminating accurate information continuously is also important as a means to return knowledge obtained in decommissioning to the international community. From the aspect of returning the results, it is also becoming more important to maintain the level of interest by responding to the changes in the international community, such as the growing interest in not only the accident and decommissioning itself but also the application to other issues.

Furthermore, in response to changes in the global energy situation in the wake of the recent Ukraine crisis, many countries have been reviewing their energy policies. Even under such circumstances, it is necessary to maintain smooth cooperative relationships with other countries toward the decommissioning of the Fukushima Daiichi NPS while gaining an accurate understanding of the updated status in the countries concerned.

It is important for NDF to disseminate and collect information accurately and in accordance with the interests of recipients through various opportunities, and to return to the international community the knowledge gained in the course of decommissioning.

6.3 Local community engagement

6.3.1 Significance and the current status of local community engagement

6.3.1.1 Basic concept

The fundamental principle for the decommissioning of the Fukushima Daiichi NPS is "Balancing between reconstruction and decommissioning". In the areas where the evacuation order has been lifted, progress toward reconstruction is gradually being made, not only by the return of residents and the resumption of business activities, but also by the promotion of migration and settlement from outside the area and new investment. While giving top priority to further reducing risks to the surrounding environment and ensuring safety, It is necessary to strengthen communication and promote coexistence with local communities to gain the trust of the community. Decommissioning should not be allowed to have a negative impact on the reconstruction process due to anxiety and distrust of decommissioning, in other words, decommissioning should never be a hindrance to reconstruction efforts.

Therefore, it is important to deepen the understanding of local residents and reassure them about the decommissioning through interactive communication: not one-way dissemination of information, but sincere listening to the concerns and questions of local residents and promptly providing them with accurate information in an easy-to-understand manner to eliminate them. In addition, to accomplish the decommissioning over a very long period of time, the continuous cooperation of companies, especially local companies, is essential. At the same time, the participation of local companies in the decommissioning project is an important pillar of TEPCO's contribution to the reconstruction of Fukushima, as it will not only revitalize decommissioning-related industries in the region and create employment and technology, but also lead to the spread of the results to other regions and industries.

6.3.1.2 Specific measures under the current situation

Based on their "Commitment to the people of Fukushima to achieve both reconstruction and decommissioning" established in March end, 2020 (hereinafter referred to as "Commitment"), TEPCO has summarized their efforts for the accumulation of decommissioning work into the following 3 categories: “① Increased participation of local enterprises”, “② Support for local enterprises to step up” and “③ Creation of new local industries”, and has started to implement them in a phased manner.

With regard to the efforts ① and ②, in cooperation with the Fukushima Innovation Coast Framework Promotion Organization and the Fukushima SOSO Reconstruction Promotion Organization, TEPCO has set up and are operating a joint consultation service to support matching between local companies interested in participating in decommissioning projects and prime contractors who are considering placing orders with local companies. In addition, it is also conducting a survey of the needs of both prime contractors and local companies regarding human resource development, and has started joint research with several universities. Moreover, the contents of the "Medium- to-Long-Term Outlook in the Decommissioning" prepared in September 2020 are being updated as necessary to reflect the progress of decommissioning work, and briefing sessions are being held for local commercial and industrial organizations, and local contractors as well as the prime contractors, paying close attention to the spread of the new coronavirus infection.

In addition, with regard to the effort ③, in order to build an integrated decommissioning project implementation system locally, from "development and design" to "manufacturing", "operation," "storage," and "recycling", TEPCO plans to establish and operate several new facilities in the 2020s, so that technologies and products of relatively high difficulty and importance, which have been ordered outside Fukushima Prefecture, including overseas, can be completed in the Hamadori region. In particular, for "development and design" to "manufacturing", TEPCO aims to create local employment, develop human resources, and build industrial and economic infrastructure by establishing a joint venture with partner companies and working closely with local businesses (announced on April 27, 2022). In October 2022, as a joint venture for fuel debris retrieval, a new engineering company was established (announced on October 3, 2022)

6.3.2 Key issues and strategies

6.3.2.1 Communication issues and strategies

Misunderstandings, concerns, and rumors caused by the inappropriate dissemination of information on the decommissioning of the nuclear power station will lead to a loss of reputation and trust in the decommissioning of the nuclear power station not only in the local community but also in society as a whole, which will not only delay the decommissioning of the nuclear power station but also hinder the reconstruction of Fukushima. For this reason, TEPCO needs to continue to take various measures to promptly communicate the current status of decommissioning in an easy-to-understand manner. In this regard, while the impact of the new coronavirus infection is expected to continue for the foreseeable future, TEPCO will make active use of tools such as virtual tour programs and online conference systems, and it is also important to strengthen communication that is possible even in non-face-to-face and non-contact situations, such as by further enhancing photo and video content.

Furthermore, the government, NDF, and TEPCO must work to build trust with local communities by providing information more carefully under appropriate coordination. Therefore, capturing opportunities to hold round-table talks and join local meetings/events, it is necessary to have direct interaction with local communities. Efforts should also be made for two-way communication by conversation, including listening to their concerns and questions carefully through events such as International Forums, and to deliver accurate information in an easy-to-understand and careful manner. In addition, it is important that the community, TEPCO, the government, NDF, and related organizations take these opportunities to deepen their knowledge together in the various changing circumstances.

In particular, some remain opposed to the disposal policy of the ALPS-treated water, and local governments and related organizations are strongly urged to provide accurate information, foster understanding, and take all possible measures to prevent rumors. For that reason, the government is implementing the measures including dissemination of information and reputational damage prevention based on the “Action Plan for Steady Implementation of the Basic Policy on the Disposal of ALPS Treated Water” (formulated on December 28, 2021, and revised on August 30, 2022).

TEPCO has been making efforts to suppress reputational damages stated in the “TEPCO Holdings’ Action in Response to the Government’s Policy on the Handling of ALPS Treated Water from the Fukushima Daiichi Nuclear Power Station” (released on April 16, 2021). It is important to continue to do its utmost to foster understanding of local communities, and to build a relationship of trust.

6.3.2.2 Issues and strategies related to the creation of a regional industrial and economic base through decommissioning

TEPCO is making various efforts to realize the "Commitment", but these efforts will not produce visible results immediately and will require a certain period of time. For the effort of "③ Creation of new local industries", construction and operation of several new facilities in the 2020s and establishment of joint ventures with partner companies were announced on October 3, 2022. It is necessary to steadily promote and strengthen these effort, because they are relatively large-scale investment and are expected to have a great economic impact on the Hamadori area. However, as advanced techniques are required to produce high-performance products, the issue is how to connect them to promoting active participation in local companies.

Therefore, for the time being, it is important to continue and strengthen the current activities in a credible manner, including "① Increased participation of local enterprises" and "② Support for local enterprises to step up". It is also important to carefully explain to local governments, commercial and industrial organizations, and other organizations concerned the location and scale of new decommissioning-related facilities, the schedule from construction to operation, and the status of considering engagement with local communities in terms of employment, cooperation and order placement, and to proceed with the activities while gaining understanding and cooperation.

With the understanding of prime contractors, it is necessary to consider specific methods of ordering and contracting that will make it easier for local companies to receive orders, and to implement these methods on a trial basis. As a result of interviews conducted with local companies in 2020, it became clear that local companies do not necessarily want to be the main contractor, but tend to want to enter the market as a subcontractor to gain technology and experience. After properly understanding the intentions and needs of these local companies, a scheme can be established to benefit both parties by not only approaching local companies, but also encouraging existing prime contractors to place orders with local companies, including technical guidance. This will contribute to the promotion of orders from local companies by adopting methods that are beneficial to both parties. In particular, it is also important to indicate that TEPCO will work together with the local community and Fukushima prefecture for the long-term decommissioning work in the future. For example, by considering initiatives that will enable local companies to receive constant and a certain scale of orders, after analyzing the details of procurement and the characteristics of local companies with relevant organizations while keeping in mind the decommissioning work. At the same time, with regard to human resource development, the Fukushima Decommissioning Engineer Training Center of the Fukushima Nuclear Energy Suppliers Council, which was established in 2018, and has been providing education of radiation protection and special education on specific matters such as low-voltage electricity handling, should be used to provide the training. In parallel, specific studies and preparations for training specifically for local companies should be accelerated. It is important to steadily promote these various efforts while responding to changes in the situation as appropriate, and to build a foundation for local industry and economy through the decommissioning project and to develop local companies and human resources.

In addition to research and development related to decommissioning, as companies from outside the region move into the region and provide technical guidance to local companies, the number of engineers and researchers visiting and staying in the region is expected to increase. Therefore, it is necessary to establish the necessary environment and support system so that such external personnel can integrate into the local community and play an active role as a member of it. In particular, it is necessary to take into consideration a wide range of functions such as daily life and education so that not only single people but also families can live together with peace of mind. In this regard, as well as promoting the return of residents, Fukushima prefecture opened "Fukushima 12-municipality Migration Support Center" that helps people move and settle in the 12 municipalities, mainly from outside the prefecture for accelerating the reconstruction of the evacuated areas by promoting wide-area migration and settlement. The prefecture has been disseminating information to people throughout the country who are interested in migration and providing various types of support to those who wish to move to the 12 cities, towns and villages. It is also important to consider the possibility of collaboration and cooperation with these local initiatives.

To steadily promote these efforts for coexistence with local community, it is essential to strengthen the organizational structure within TEPCO and to have close cooperation between each department. TEPCO has been reorganizing itself to set up specialized departments for regional symbiosis, and efforts to promote local industries through decommissioning are gradually moving forward, and gaining a certain level of recognition from the local community. While keeping this trend advancing steadily, it is important to further strengthen internal efforts as necessary for promoting local industries.

Moreover, it is necessary to further strengthen cooperation and collaboration with local governments, including Fukushima Prefecture, and local related organizations, including the Fukushima Innovation Coast Framework Promotion Organization and the Fukushima SOSO Recovery Promotion Organization, which are operating a joint consultation service and co-hosting matching business meetings. NDF will provide appropriate support to TEPCO's efforts for regional symbiosis, and will strive to strengthen cooperation and collaboration with local governments and related organizations.